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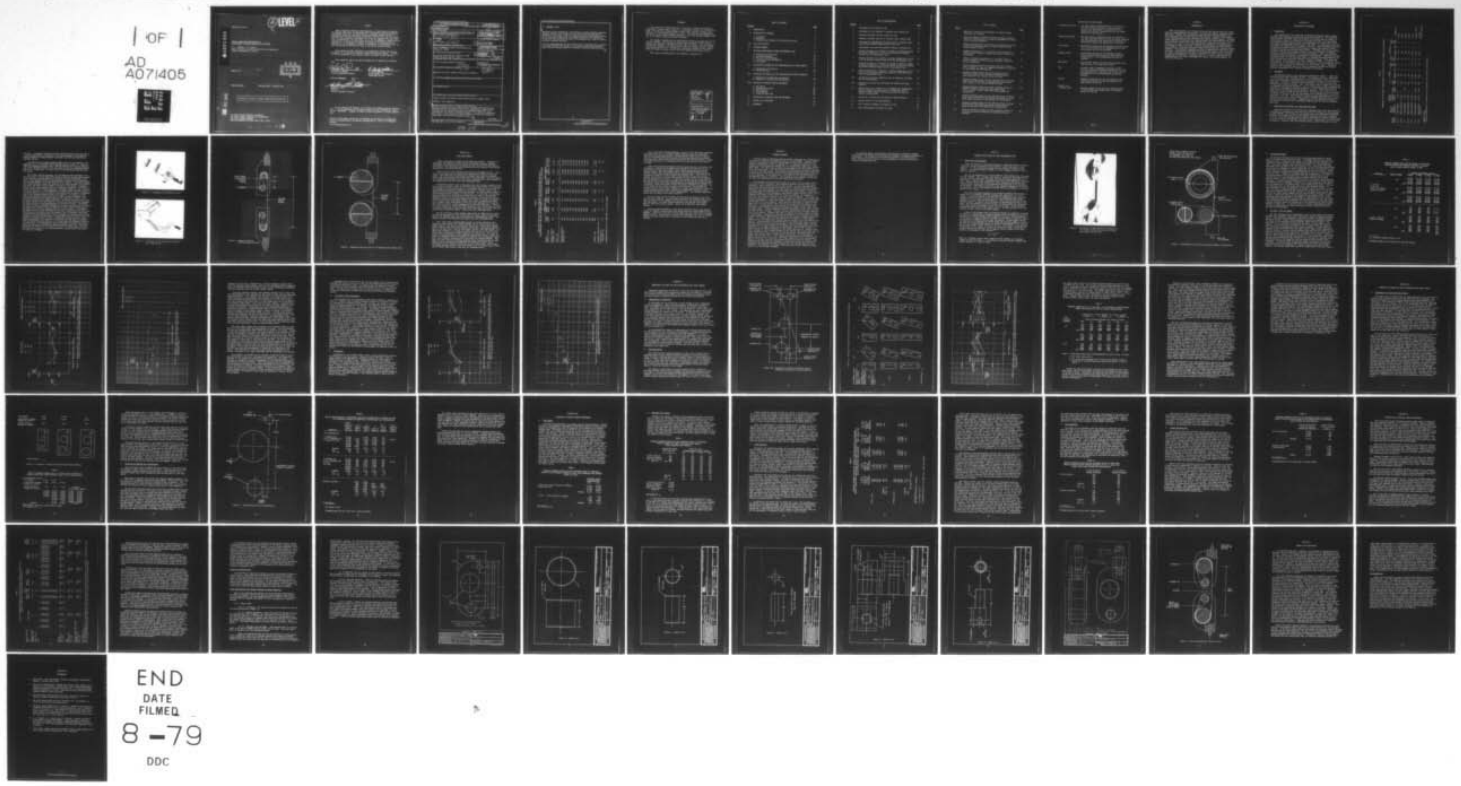

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KEVLAR PROPERTIES INVESTIGATION
DEVELOPMENT OF KEVLAR TENSILE TEST METHODS

S. L. Goodwin, N. J. Abbott
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Testing procedures which are used for nylon parachute materials have not been satisfactory for testing their Kevlar counterparts. Kevlar's high strength and low elongation can result in premature breaks and, thus, inordinately low values of breaking strength. In an effort to understand the causes of these spuriously induced failures, a study was designed to investigate the reasons for premature breaks.

(continued)

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20. **Abstract** (cont)

Extensive tensile testing with a wide variety of Kevlar parachute component materials has led to the adoption of new jaws and testing techniques designed to give breaks in the free length with nearly simultaneous failure of all warp yarns, high values of breaking strength and low variability. The new jaws are described and their use illustrated for a range of typical parachute component materials.

A set of design drawings for the optimized jaws is included, and a proposed text which describes the procedure to be used in tensile testing Kevlar narrow fabrics has been drafted for inclusion in Military Specifications.

FOREWORD

This report was prepared by FRL, A Division of Albany International Corporation, Dedham, Mass., under U. S. Government Contract No. F33615-78-C-3406. The work was initiated under Project 2402, and was conducted from February 13, 1978 through January 31, 1979. The contract was administered by the Air Force Flight Dynamics Laboratory, Air Force Systems Command, with Mr. W. R. Pinnell acting as Project Engineer.

Mr. Norman J. Abbott was the FRL Associate Director responsible for the overall program. The laboratory studies were carried out by Mr. James G. Donovan, Mr. Stephen L. Goodwin and Miss Loren E. Atkins. For many helpful discussions throughout the course of the work, the authors wish to express their appreciation to Dr. John Skelton, Associate Director at FRL, and Dr. Milton M. Platt, Director at FRL, who also handled contractual matters.

This report was submitted by the authors in January 1979.

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DEFINITIONS OF BREAK TERMS

Simultaneous Failure	- Specimen rupture characterized by the rupture of all load carrying elements in the structure at exactly the same moment as determined by the visible and audible characteristics of the break observed by the operator.
Sequential Failure	- Specimen rupture characterized by the rupture of all load carrying elements in the structure occurring non-simultaneously over some finite time period as determined visually and audibly by the operator.
Clean Break	- Simultaneous failure of the specimen occurring parallel to one filling yarn and perpendicular to the longitudinal axis of the specimen.
Diagonal Break	- Simultaneous failure of the specimen occurring across multiple filling yarns at some angle not perpendicular to the longitudinal axis of the specimen.
Edge Break	- Simultaneous failure of most of the specimen with some portion of one edge left intact.
Tear	- A special case of sequential failure in which the yarn breaks are normally initiated at one edge and proceed along a line which may or may not be perpendicular to the longitudinal axis of the specimen.
Cutting	- Specimen rupture within the jaw caused by high transverse pressures at some inconsistency or small radius in the jaw.
Break at the Tangent Point	- Specimen rupture at the point of initial contact of the specimen free length with the snubbing surface of the jaw.

SECTION I

INTRODUCTION

With the increasing use of woven Kevlar narrow fabrics there is a great need for standardization of methods to evaluate the rupture strength of such materials. Tensile test methods have been optimized and standardized for other materials such as nylon woven narrow fabrics. However, these methods do not seem suitable for the extremely high modulus Kevlar fabrics. The most common problems encountered when testing Kevlar with these methods are incomplete failure of warp yarns, non-simultaneous failure of warp yarns, and failure at the jaw. All of these factors can contribute to unrealistically low values of rupture strength. Military Specifications for Kevlar woven narrow fabrics, give both a specific weave construction and a minimum rupture strength. Poor testing techniques can make it impossible to meet both specifications. Significantly different test techniques between test facilities can cause discrepancies which make it difficult to define the true rupture strength of the material. Obviously there is a need for optimization and standardization of testing techniques for Kevlar woven narrow fabrics, as there was for nylon.

SECTION II

DESCRIPTION OF PROGRAM

A. Objectives

The objectives of this work were to develop optimized tensile testing apparatus and techniques for testing Kevlar narrow fabrics. The apparatus and techniques developed should be suitable for testing fabrics ranging in width from 1/2 inch to 2 inches and in strength from 200 to 20,000 pounds. The apparatus should effect breaks in the specimen free length which occur with nearly simultaneous failure of all warp yarns. In conjunction with this, techniques for installing the specimen in the jaw, inserting padding material and applying tension, should be optimized to produce the highest average tension at failure with minimal data scatter. Candidate test fixture design variations should include fixture width, radius of curvature of snubbing surfaces, and relative position of gripping elements. Each test condition evaluation should be based on a minimum of 3 good breaks. Comparison of test variations shall be with data base values of breaking strength generated for each material using currently standard testing techniques. This data base value should be an average of 25 tests. However, in order to conserve time and material, 10 good breaks shall be used instead of 25 if variability is low enough to ensure statistical credibility in the average value. Optimized apparatus and techniques should be used to generate a second data base to quantify improvements over currently standard test methods.

B. Materials

The materials used in the testing are presented in Table 1. These constructions were taken from MIL-T-87130.[1] The materials range in width from 1/2 to 2 inches and in strength from 250 to 15,000 pounds. There is also a wide range of weights, thicknesses and constructions present in this group of materials. In order to conserve time and material, two constructions were selected for extensive testing. The 2 inch wide, 1,000 lb ribbon was selected to represent the lighter materials. The 1-1/8 inch wide 13,500 lb webbing was selected to represent the heavier materials. Both of these materials have been subject to problems with bad breaks in the past. The 2 inch 1,000 lb ribbon is subject to edge breaks and tears. The 1-1/8 inch 13,500 lb webbing is subject to cutting in the jaw and breaks at the tangent point of the line of action to the jaw. These materials should be good representatives of the materials to be used in the testing, and the problems associated with tensile testing Kevlar narrow fabrics. Compatibility of the techniques developed for these two materials was subsequently demonstrated for all the remaining materials.

C. Reference Test Methods for Obtaining Data Base

There are currently two fixtures and techniques which were used initially to establish reference data base values of tensile strength for the materials in this program. The double pin jaw (supplied to us by AFFDL and henceforth referred to as AFFDL pin jaws) and wrapping technique are shown in Figures 1 and 3. This jaw has been used for testing materials with rated strengths up to 5,000 lb and can accommodate materials up to 2 inches wide. As can be seen in Figure 3, a cotton liner was inserted between layers of Kevlar on one of

TABLE 1

MATERIALS TO BE USED IN DEVELOPMENT OF TENSILE TESTING APPARATUS AND TECHNIQUE

MIL-T-87130*	Type of Kevlar Material	Nominal Tensile Strength (lb)	Width (inch)	Warp				Filling				Weave
				Total Ends	Denier	Ply	Twist per Inch	Picks per Inch	Denier	Ply	Twist per Inch	
XI-3	Light Ribbon	400	2	60	200	1	2	50	200	1	0	Plain
XI-9a	Medium Ribbon **	1,000	2	164	200	1	6	46	200	1	0	Plain
I-1	Light Webbing	250	1/2	42	200	1	6	35	200	1	0	Plain
VI-4	Medium Webbing	1,000	1	102	400	1	5	31	400	1	0	Plain
VI-9	Medium Webbing	6,000	1	44	1,500	3	1.8	10	1,500	1	0	Plain
X-11	Heavy Webbing	15,000	1-3/4	121	1,500	3	1.8	13	1,500	1	0	Double Plain
VII-6	Heavy Webbing Coating **	13,500	1-1/8	140	1,500	2	1.8	14	1,500	2	0	5/1 HBT Center Reversal

*Type - Class.
**Used as representative materials for apparatus and technique development.

the pins. A standard technique used with these jaws was to stop the test at a load of approximately 15 percent of the rated strength of the material. After hesitation for approximately 30 seconds, the test was continued to specimen rupture.

For materials with rated strengths above 5,000 lb, the reference test apparatus was a 4 inch diameter split capstan shown in Figure 2.[2] Figure 4 shows the wrapping technique used. This jaw was used for testing materials with rated strengths between 5,000 and 20,000 lb and can accommodate materials up to 4 inches wide. No cotton liner or hesitation was used with this jaw system.

With either testing technique, the jaw speed was kept constant at one inch per minute. The specimen free length or distance between tangent points on the jaw was also kept constant at 12 inches for both techniques. This gave a total specimen length of approximately 36 inches with the double pin jaws and approximately 50 inches with the split capstans. The split capstans are rigidly attached, except for rotation on the screw threads of the attachment pins, and offer little freedom of movement for alignment. Alignment during the test was provided only by the universal connector to the load cell of the Instron Tensile Testing Machine. Alignment before the test is therefore very critical. It was accomplished by standing back from the Instron in a position where the line of sight to the Instron line of action is perpendicular to the imaginary working plane of the machine. By standing in this position and moving slightly from side to side, accurate alignment of the outer side plates can be achieved quickly and easily with the eye. This procedure was carried out before each test. The double pin jaws have a third pin which attaches the side plates to a steel block and allows for alignment by rotation about an axis perpendicular to the line of action. The double pin jaws also have a standard attachment pin between the block and the Instron universal joint similar to the one used on the split capstans which allows for rotation on the screw threads about the line of action. An alignment procedure similar to that described for the split capstan jaws was also used for double pin jaws before each test because, due to frictional restraints, these self-aligning capabilities would not always give complete and accurate alignment once the test has begun. A misalignment due to rotation of one jaw relative to another about the line of action would cause an uneven length effect proportional to the width of the material and the angle of rotation. This would produce uneven tensions in the warp yarns and premature rupture of the edge yarns. The specimen must also be centered on the jaw and multiple layers of wrap must be centered on each other before each test. The cotton liner must be wrinkle free and completely cover the inside layer of Kevlar. By carefully following all of these procedures, variability and bad breaks were kept to a minimum.

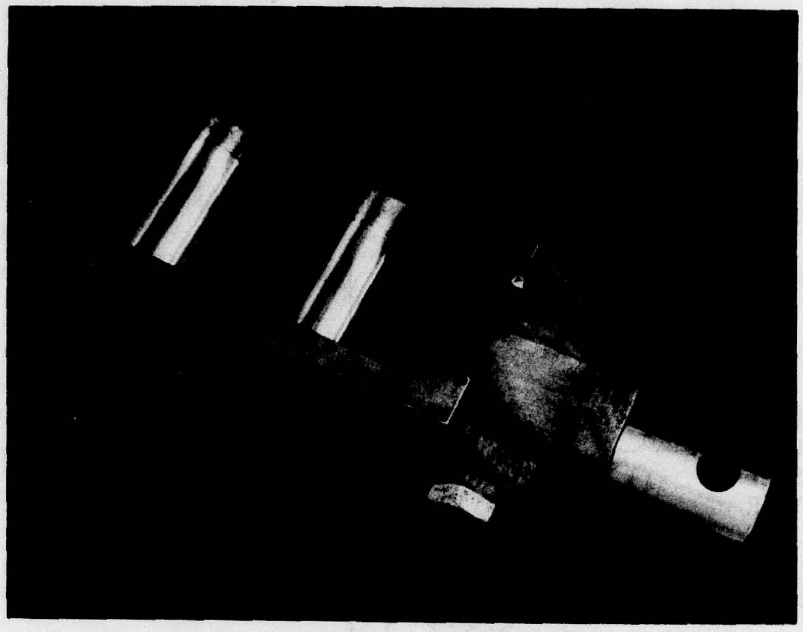


Figure 1. Photograph of the AFFDL Pin Jaw

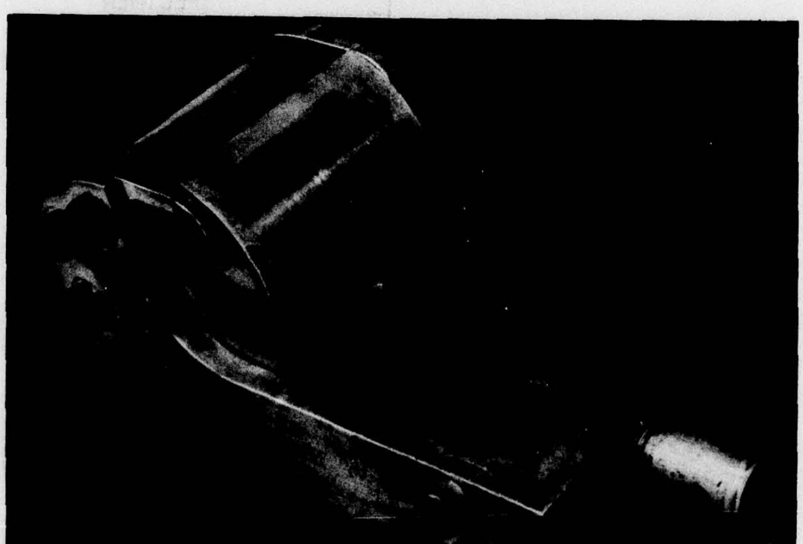


Figure 2. Photograph of the Standard 4" Diameter
Split Capstan Jaw

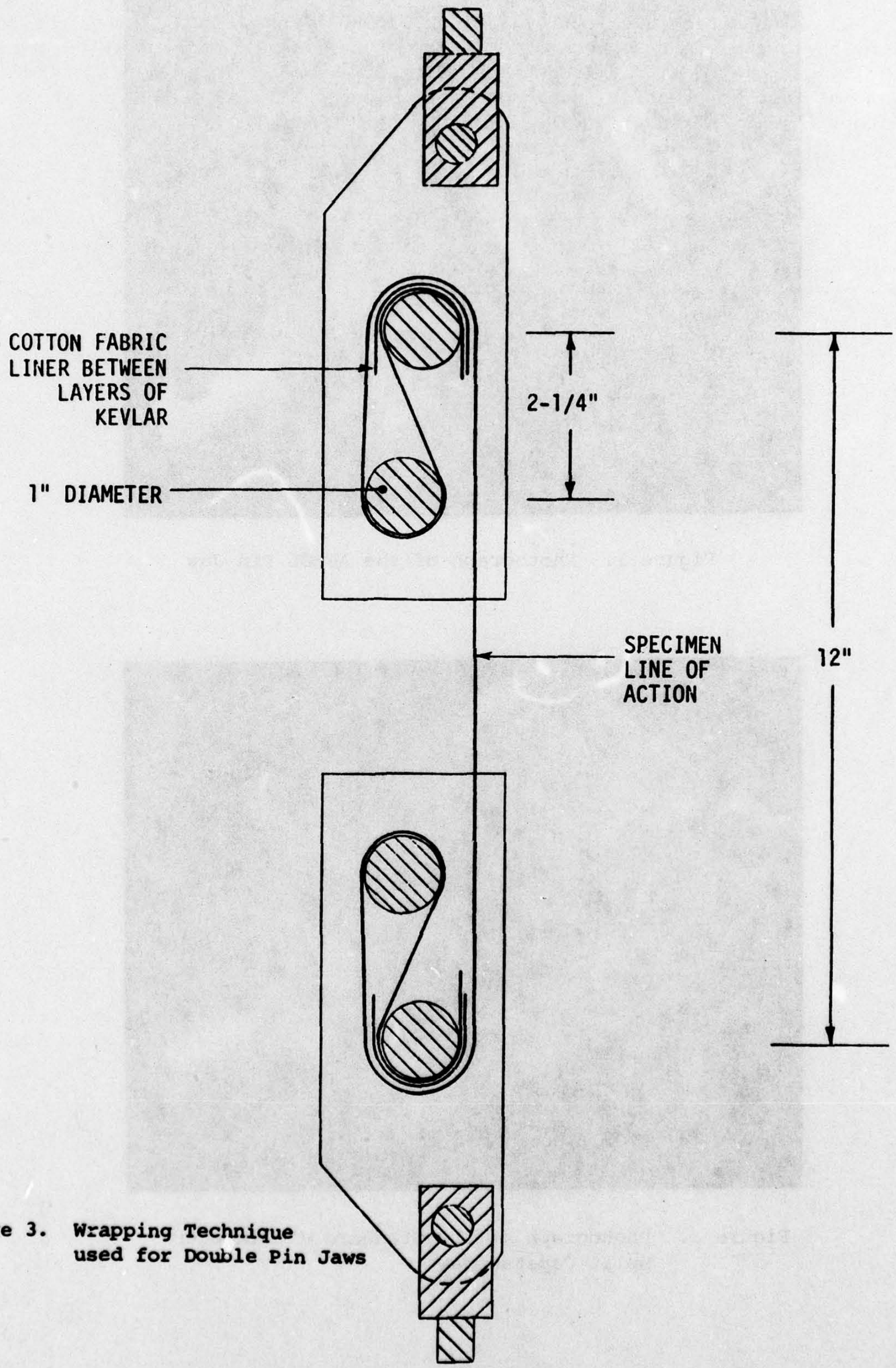


Figure 3. Wrapping Technique used for Double Pin Jaws

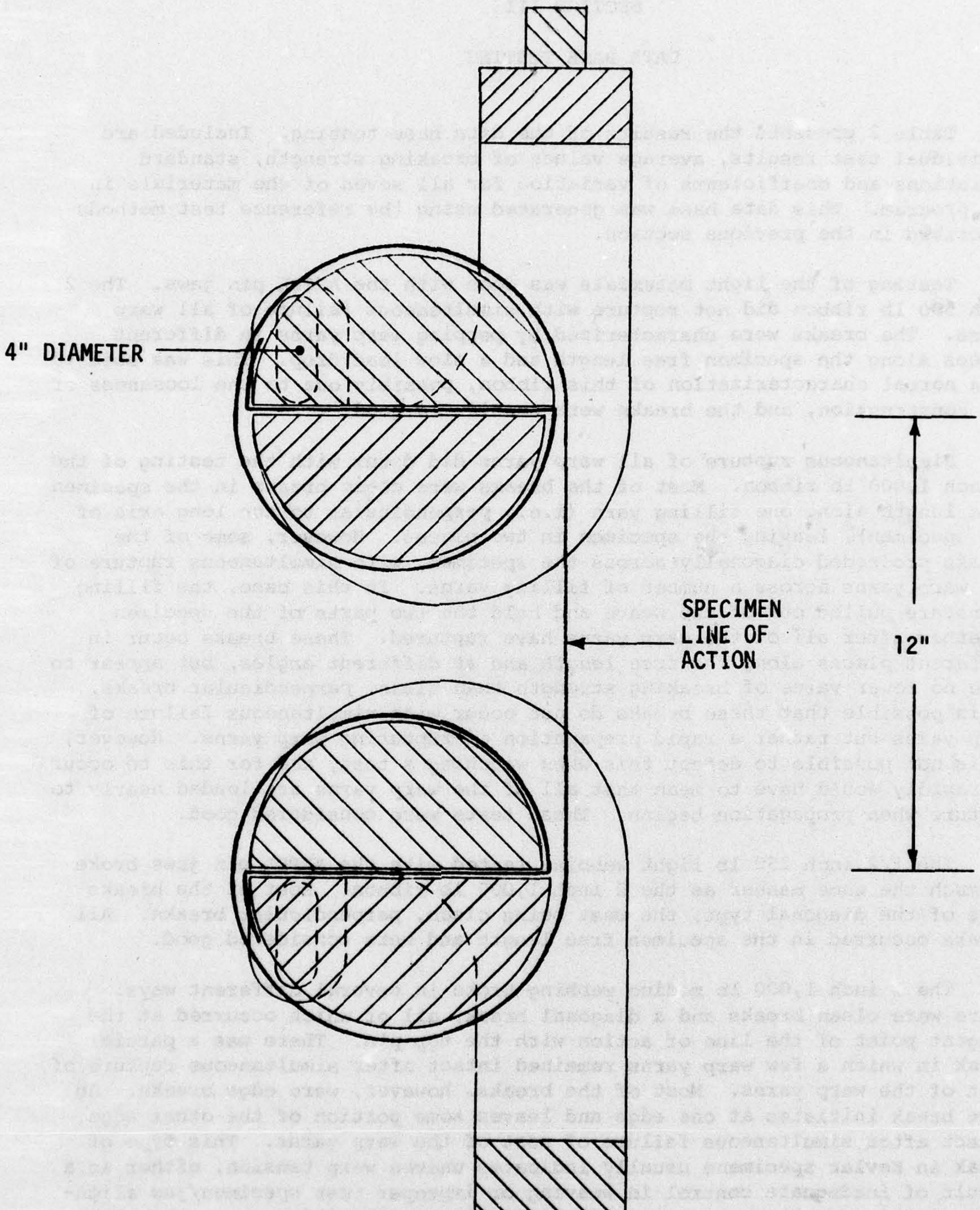


Figure 4. Wrapping Technique used for 4" Diameter Split Capstan Jaws

SECTION III

DATA BASE TESTING

Table 2 presents the results of the data base testing. Included are individual test results, average values of breaking strength, standard deviations and coefficients of variation for all seven of the materials in the program. This data base was generated using the reference test methods described in the previous section.

Testing of the light materials was done with the AFFDL pin jaws. The 2 inch 500 lb ribbon did not rupture with simultaneous failure of all warp yarns. The breaks were characterized by popping warp yarns in different places along the specimen free length and a slow load drop. This was said to be a normal characterization of this ribbon, possibly due to the looseness of the construction, and the breaks were considered good.

Simultaneous rupture of all warp yarns did occur with the testing of the 2 inch 1,000 lb ribbon. Most of the breaks were clean breaks in the specimen free length along one filling yarn (i.e., perpendicular to the long axis of the specimen), leaving the specimen in two pieces. However, some of the breaks proceeded diagonally across the specimen, with simultaneous rupture of the warp yarns across a number of filling yarns. In this case, the filling yarns are pulled out of the weave and hold the two parts of the specimen together after all of the warp yarns have ruptured. These breaks occur in different places along the free length and at different angles, but appear to give no lower value of breaking strength than clean, perpendicular breaks. It is possible that these breaks do not occur with simultaneous failure of warp yarns but rather a rapid propagation of rupturing warp yarns. However, it is not possible to detect this when watching a test, and for this to occur so rapidly would have to mean that all of the warp yarns are loaded nearly to rupture when propagation begins. These tests were considered good.

The 1/2 inch 250 lb light webbing tested with the AFFDL pin jaws broke in much the same manner as the 2 inch 1,000 lb ribbon. Most of the breaks were of the diagonal type, the rest being clean, perpendicular breaks. All breaks occurred in the specimen free length and were considered good.

The 1 inch 1,000 lb medium webbing broke in several different ways. There were clean breaks and a diagonal break, all of which occurred at the tangent point of the line of action with the top pin. There was a partial break in which a few warp yarns remained intact after simultaneous rupture of most of the warp yarns. Most of the breaks, however, were edge breaks. An edge break initiates at one edge and leaves some portion of the other edge intact after simultaneous failure of most of the warp yarns. This type of break in Kevlar specimens usually indicates uneven warp tension, either as a result of inadequate control in weaving or improper test specimen/jaw alignment, and is usually associated with low values of breaking strength. However, for these tests the breaking strength values associated with the edge breaks were not statistically different from breaking strength values obtained from other types of breaks seen in this test series. Also, since all breaks occurred either in the free length or at the tangent point of the line of action with the pin, they were all considered good.

TABLE 2

DATA BASE VALUES OF BREAKING STRENGTH FOR SEVEN DIFFERENT KEVLAR 29 CONSTRUCTIONS TO BE USED IN DEVELOPMENT OF KEVLAR TENSILE TESTING TECHNIQUES

	AFFDL Pin Jaw				Split Capstan		
Kevlar Material Type	Light Ribbon	Medium Ribbon	Light Webbing	Medium Webbing	Medium Webbing	Heavy Webbing	Heavy Webbing Coated
Nominal Tensile Strength (lb)	500	1000	250	1000	6000	15,000	13,500
Width (in)	2	2	1/2	1	1	1-3/4	1-1/8
Measured Breaking Strength (lb)	440	930	343	1080	5500	16,600	14,500
	425	1010	345	1130	6000	17,000	15,000
	430	1060	350	1190	6150	15,900	14,200
	425	980	346	1170	6100	16,700	14,200
	460	980	352	1160	6050	17,100	14,600
	475	1000	338	1220	6400	17,200	14,100
	475	1060	345	1170	5800	16,600	13,600
	450	1080	353	1190	5750	16,500	13,200
	480	1090	333	1250	6100	16,900	13,600
	470	1080	347	1200	5900	16,800	13,900
	460						
	455						
Average (lb)	454	1027	345	1176	5975	16,730	14,090
Standard Deviation (lb)	20	54	6	47	250	371	536
Coefficient of Variation (%)	4.4	5.3	1.8	4.0	4.2	2.2	3.8

Crosshead speed for all tests was 1 inch per minute.

The 1 inch 6,000 lb medium webbing, as well as the other heavy materials, was tested with the 4 inch diameter split capstans using the procedures outlined in the previous section. Breaks were all either clean or partial with no statistical difference between the breaking strength values associated with each. Most of the breaks occurred in the free length with a couple of breaks occurring at the tangent point of the line of action with one of the jaws.

There were problems associated with the testing of the 1-1/8 inch 13,500 lb webbing. Cutting of the sample was occurring at the front of the jaw where the inner wrap bends around a small radius and enters between the capstan halves. This was possibly due to the increased stiffness of the material after being coated with polyvinyl butyral (PVB). This problem was overcome by inserting a cotton fabric liner between the jaw and and the webbing at the point of cutting and between the free length of the specimen and the webbing at this point. It was also necessary to use a long tail at the back of the jaw to force the movable half of the capstan forward and keep the specimen free length from bearing against the webbing where cutting was occurring. Using this method, cutting was almost completely eliminated. All of the breaks in this series occurred on the capstan. The specimen was rupturing on top of the curved surface of the jaw, approximately 90° past the initial tangent contact point, indicating a substantial jaw effect which might have affected the test results significantly. The remaining materials tested did not exhibit this mode of failure.

The 1-3/4 inch 15,000 lb webbing did not break as poorly as the 1-1/8 inch 13,500 lb webbing. Only one break occurred at the tangent point of the line of action with the capstan, and this was also the only clean break in the test series. All other breaks occurred in the specimen free length. Most of these were partial breaks. Two of the breaks were edge breaks, however.

As can be seen from Table 2, most of the materials tested gave average values of breaking strength which were higher than the rated strength of the material. Only the 2 inch 500 lb light ribbon and the 1 inch 6,000 lb medium webbing did not. There seemed to be room for improvement not only in average rupture load and variability of results but also in mode and position of failure.

SECTION IV

MAXIMUM STRENGTH

The first step in developing tensile testing techniques for a material was to attempt to establish the maximum strength of the material. Typical translational efficiencies for Kevlar constructions of this type tested with the reference techniques is about 70 percent.[3,4] If strength losses due to test methods could be eliminated, perhaps the true translational efficiency would be much higher. The theory was to weaken the specimen in the free length by cutting a few warp yarns. Jaw effects could be eliminated by forcing the specimen to break in the free length. By calculating the translational efficiency based on the number of load bearing yarns in the weakened area and applying this to an uncut specimen, it was hoped that a true value of the rupture strength of the material could be calculated. This method has been effective in the past for some other materials but it had not been done with Kevlar.

This procedure was followed with both the 2 inch 1,000 lb ribbon and the 1-1/8 inch 13,500 lb webbing. Many different methods of cutting were used. Initially a rotary blade was used for the cutting. It was first checked for consistency with both materials by making cuts of accurately measured lengths, parallel to the filling yarns, into the edges of a small sample of material. The sample was then unraveled and the severed yarns were counted. After sufficient development of this technique, some tensile testing specimens were cut at midlength and tensile tested using the reference methods. No increase in efficiency was realized with the 1-1/8 inch 13,500 lb webbing. The ribbon was extremely susceptible to tearing after the edges had been cut and the efficiency dropped tremendously. After this attempt failed, warp yarns were counted and cut by hand on the next samples. Again the cuts were equal in length on both edges along the same filling yarn line and the results were the same for both materials. In an attempt to avoid tearing of the ribbon, several small cuts were made along different filling yarns toward the center of the ribbon leaving the edges intact. Several different cutting configurations were used, all with the same results as before. Several circular cutting dies of various diameters were then purchased. Attempts were made to cleanly cut circles from the center of the material. Although the cutting was difficult, the consistency of number of yarns severed was adequate when warp yarns were counted in small samples as before. The results were still the same with no increase in translational efficiency for the webbing and tearing from the circular cut to the edge of the ribbon. Further attempts to avoid tearing of the ribbon were made by cutting each edge starting at the same filling yarn, cutting a gradual taper into the material until a certain distance was reached, and cutting gradually out to the edge again at the same filling yarn on both edges. The cut was 8 inches in length and gave a smooth transition to the necked down section. However, with only 2 inches of intact ribbon between the cut and the jaw on both ends, the cut yarns contributed little at the jaw and pulled through the weave before the ribbon broke cleanly with a slight loss in efficiency. This same type of gradual cut was done over a 2 inch length but the results were essentially the same as those for the 8 inch cut. The final attempt was to cut in from each edge on the ribbon along one filling yarn and then cut away the selvage. The outermost edge yarn was then unraveled 5 inches from the cut and each yarn in succession was unraveled a lesser distance until all severed yarns had been unraveled. The specimen was tensile tested and gave results similar to those found in the two previous attempts.

As mentioned before, the purpose of this work was to quantify strength losses due to jaw effects during testing and determine the maximum efficiency of the material. All attempts at this failed to produce a reliable estimate. Since this data was not crucial to the development of tensile testing techniques, this work ended here.

SECTION V

VARIABLE RADIUS/ANGLE OF WRAP EXPERIMENTAL JAWS

A. Description of Apparatus

Among the factors in jaw design believed to influence breaking strength values are radius of curvature of any snubbing surface and angle of wrap around it. A set of jaws was designed for the purpose of studying these effects. The jaws are shown in Figure 5 and the wrapping technique used is shown in Figure 6.

The top jaw consisted of a 10 inch diameter drum through which slots were cut 180° opposed. As is evident from Figure 6, the end of the sample passed through the drum, after one full wrap, and was positioned underneath the outer wrap in order to get a reversing action for a self-tightening configuration. Because the 10 inch drum did not offer clamping action between the capstan halves as with the 4 inch diameter split capstans, it was necessary to use almost a 180° wrap of the tail to get ultimate clamping at the end of the specimen. The 10 inch diameter drum was used in an attempt to discourage breaks at this point.

The bottom jaw which attached to the Instron crosshead was designed to accept one of 4 different snubbing surfaces with radii of 1, 2, 3, or 4 inches. As shown in Figure 6, the specimen was wrapped part way around the snubbing surface and the end was held by a 4 inch diameter split capstan mounted on an arm. The arm was designed to rotate about the center of the snubbing surface in order to vary the angle of wrap around the snubbing surface. The bolt pattern on the side plates and drums allowed for adjustment of the wrap angle in increments of 45° from 45° to 180°. It was expected that breaks would occur at the tangent point of the line of action with the snubbing surface or the 4 inch split capstan.

A plot of the average value of breaking strength as a function of radius of curvature coupled with an estimated maximum value of breaking strength was expected to yield the minimum usable radius of curvature. An understanding of the effect of angle of wrap is necessary for the design of variable radius of curvature or variable friction type jaw systems. In any capstan design, the objective is to provide for tension decay and ultimate clamping in such a way that the stress gradient along the length of the specimen in the jaw will not be high enough to cause failure in the jaw. The tension in the specimen at any point on the capstan is related to the angle of wrap, coefficient of friction between the specimen and the capstan and the tension in the free length of the specimen by the equation:[5]

$$T_\theta = T_o e^{-\mu\theta}$$

where T_θ = specimen tension after wrapping around capstan; T_o = specimen tension at the pulled end; μ = coefficient of friction between specimen and capstan surface; θ = angle of wrap.

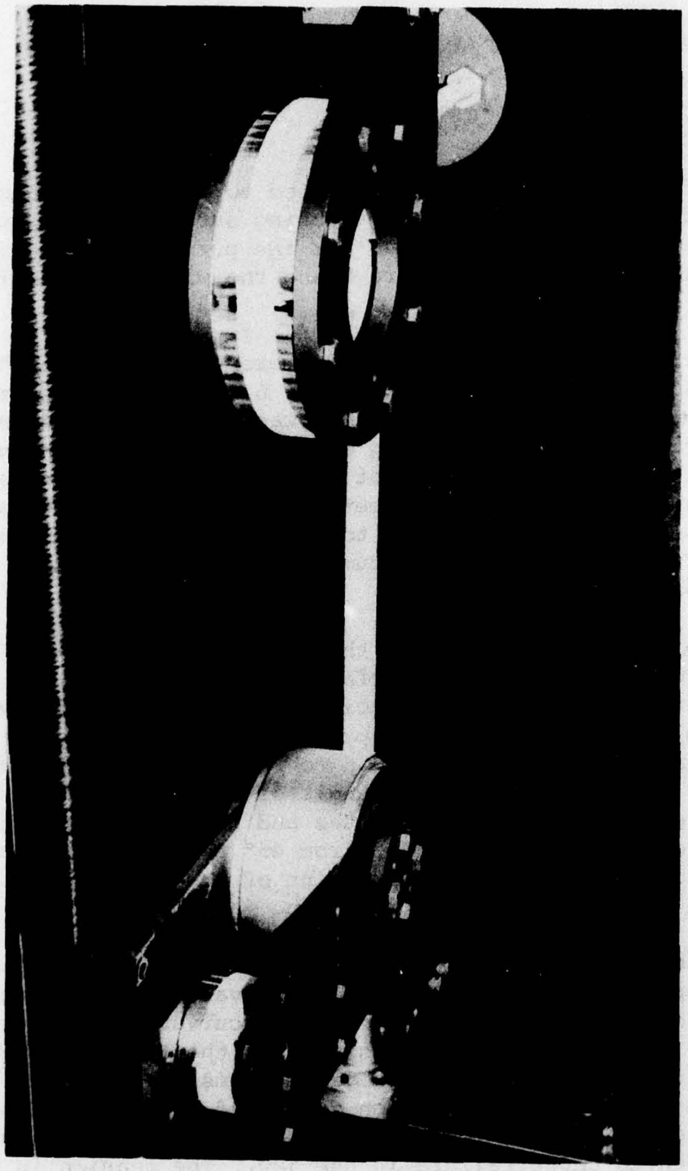


Figure 5. Photograph of Experimental Jaw Setup with 10" Diameter Split Drum Jaw and Variable Radius/Angle of Wrap Jaw

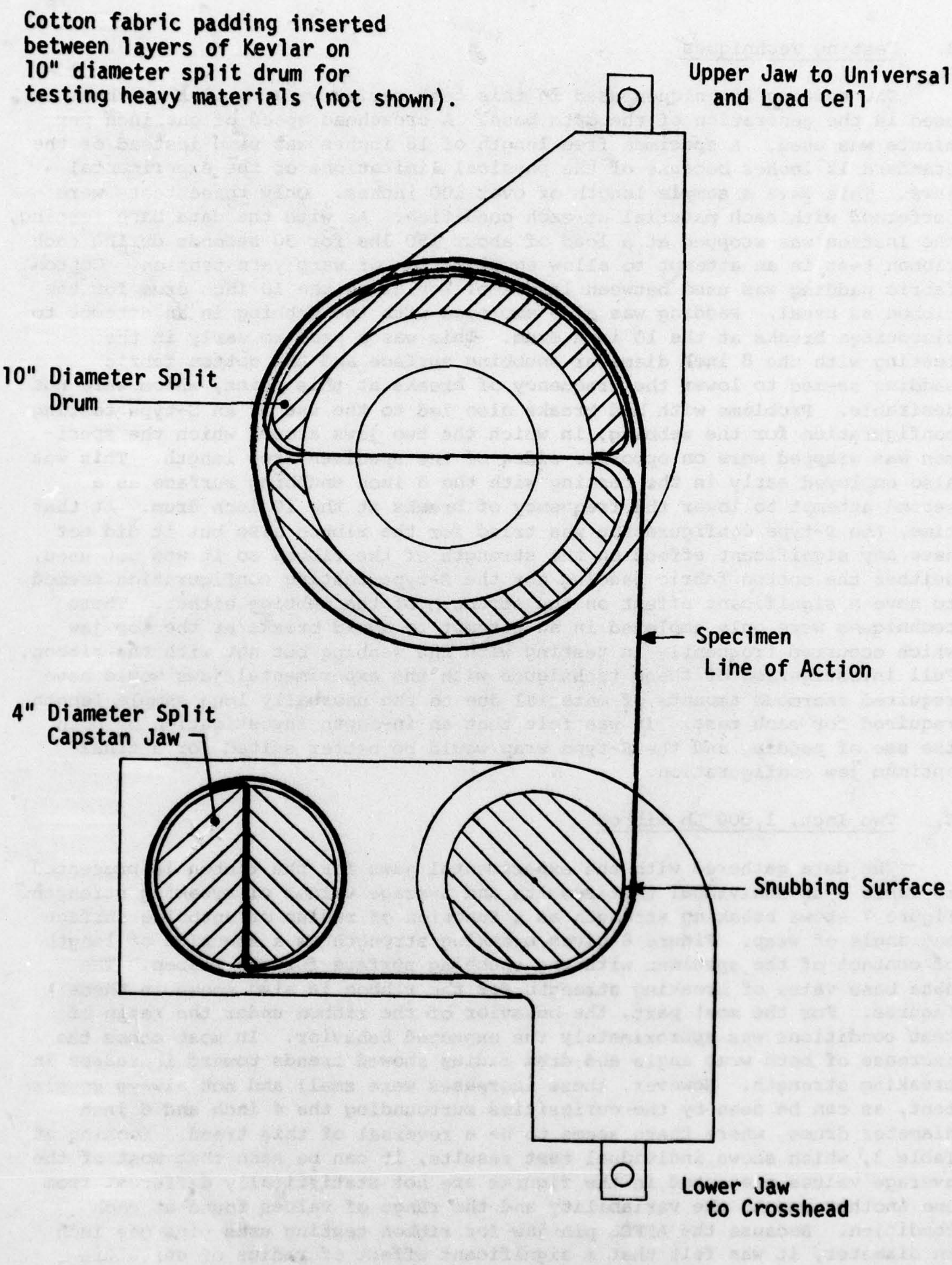


Figure 6. Experimental Jaw Setup and Specimen Wrapping Configuration

B. Testing Techniques

The testing techniques used in this test series were similar to those used in the generation of the data base. A crosshead speed of one inch per minute was used. A specimen free length of 18 inches was used instead of the standard 12 inches because of the physical limitations of the experimental jaws. This gave a sample length of over 100 inches. Only three tests were performed with each material at each condition. As with the data base testing, the Instron was stopped at a load of about 150 lbs for 30 seconds during each ribbon test in an attempt to allow equalization of warp yarn tension. Cotton fabric padding was used between layers of Kevlar on the 10 inch drum for the ribbon as usual. Padding was also employed with the webbing in an attempt to discourage breaks at the 10 inch drum. This was a problem early in the testing with the 8 inch diameter snubbing surface and the cotton fabric padding seemed to lower the frequency of breaks at this point, which were not desirable. Problems with bad breaks also led to the use of an S-type testing configuration for the webbing, in which the two jaws around which the specimen was wrapped were on opposite sides of the specimen free length. This was also employed early in the testing with the 8 inch snubbing surface as a second attempt to lower the frequency of breaks at the 10 inch drum. At that time, the S-type configuration was tried for the ribbon also but it did not have any significant effect on the strength of the ribbon so it was not used. Neither the cotton fabric padding nor the S-type testing configuration seemed to have a significant effect on the strength of the webbing either. These techniques were only employed in an attempt to avoid breaks at the top jaw which occurred frequently in testing with the webbing but not with the ribbon. Full investigation of these techniques with the experimental jaws would have required enormous amounts of material due to the unusually long sample length required for each test. It was felt that an in-depth investigation of both the use of padding and the S-type wrap would be better suited for a final optimum jaw configuration.

C. Two Inch, 1,000 Lb Ribbon

The data gathered with the experimental jaws for the ribbon is presented in Table 3 as individual test results and average values of breaking strength. Figure 7 shows breaking strength as a function of radius of snubbing surface and angle of wrap. Figure 8 gives breaking strength as a function of length of contact of the specimen with the snubbing surface for the ribbon. The data base value of breaking strength for the ribbon is also shown in these figures. For the most part, the behavior of the ribbon under the range of test conditions was approximately the expected behavior. In most cases the increase of both wrap angle and drum radius showed trends toward increases in breaking strength. However, these increases were small and not always consistent, as can be seen by the curiosities surrounding the 4 inch and 8 inch diameter drums, where there seems to be a reversal of this trend. Looking at Table 3, which shows individual test results, it can be seen that most of the average values presented in the figures are not statistically different from one another due to the variability and the range of values found at each condition. Because the AFFDL pin jaw for ribbon testing uses pins one inch in diameter, it was felt that a significant effect of radius of curvature would not be seen with diameters of 2 inches or more as was used in this testing. The contact length plot, which is a combination of both the radius

TABLE 3

BREAKING STRENGTH DATA FOR TWO KEVLAR 29 STRUCTURES
TENSILE TESTED OVER SNUBBING SURFACES OF VARIOUS
RADII THROUGH VARIOUS ANGLES OF WRAP

Specimen	Angle of Wrap		Radius of Snubbing Surface 1 Inch	2 Inch	3 Inch	4 Inch
			13,800	15,100	14,600	14,300
	45°		14,000	15,100	14,700	14,600
			13,700	15,000	14,000	14,700
		Avg.	13,833	15,067	14,433	14,533
1 1/8 Inch 13,500 lb Kevlar 29 Webbing Coated with PVB			14,000	14,900	15,000	15,000
	90°		13,700	15,200	14,900	15,200
			14,200	14,400	15,100	15,100
		Avg.	13,967	14,833	15,000	15,100
			14,300	14,700	15,000	15,500
	135°		14,400	14,800	15,200	15,500
			14,200	14,700	14,800	14,600
		Avg.	14,300	14,767	15,000	15,200
			830	820	860	------
	45°		900	850	840	------
			830	870	910	------
		Avg.	853	847	870	------
			860	880	850	900
2 Inch 1,000 lb Kevlar 29 Ribbon	90°		890	780	860	910
			800	840	880	890
		Avg.	850	833	863	900
			920	820	840	800
	135°		860	840	920	940
			930	810	920	780
		Avg.	903	823	893	830
						838

All breaking strength values in lb.

Crosshead speed for all tests was 1 inch per minute.

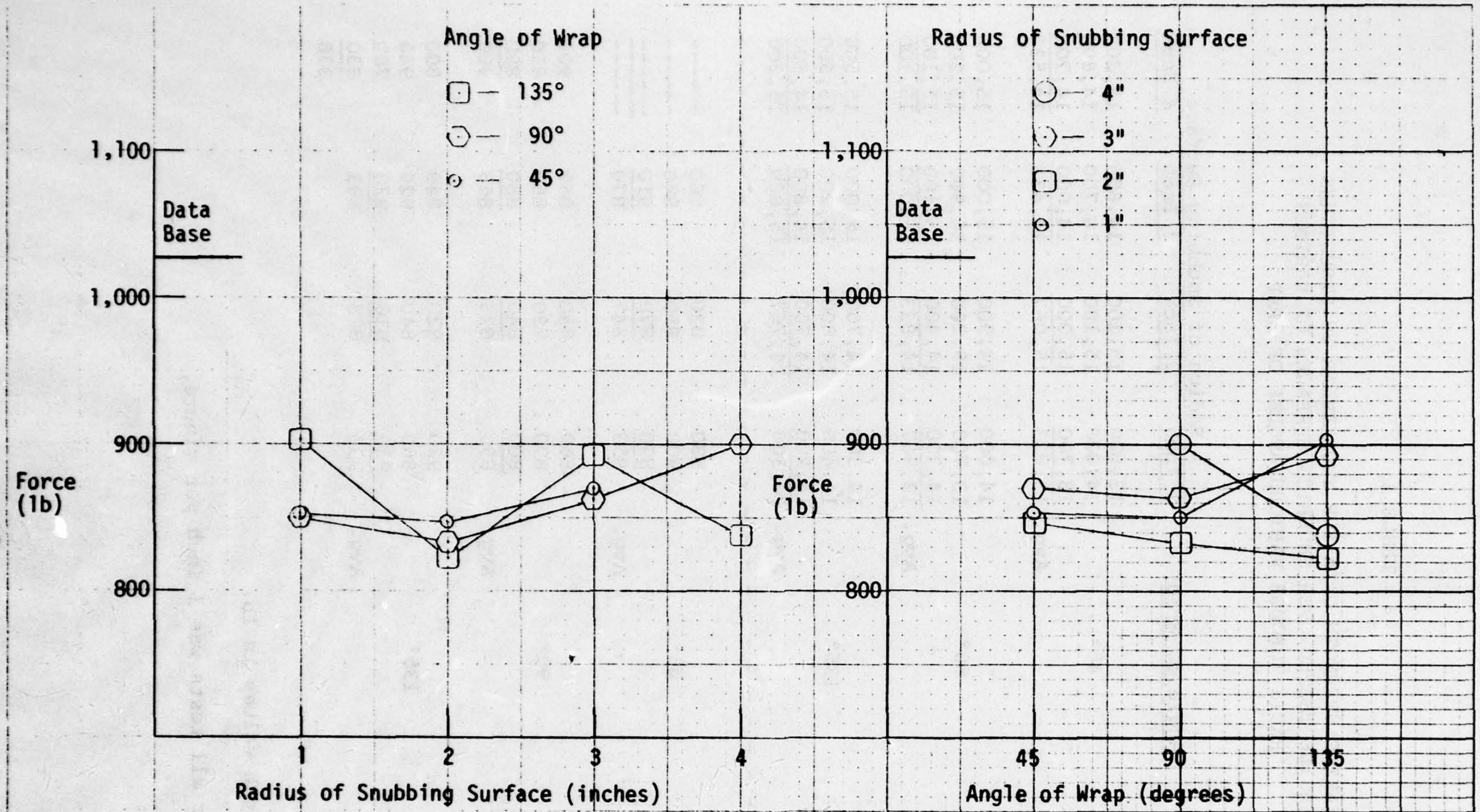


Figure 7. Breaking Strength as a Function of Radius of Snubbing Surface and Angle of Wrap for a 2 Inch 1,000 lb Kevlar 29 Ribbon Tested with the Experimental Jaws

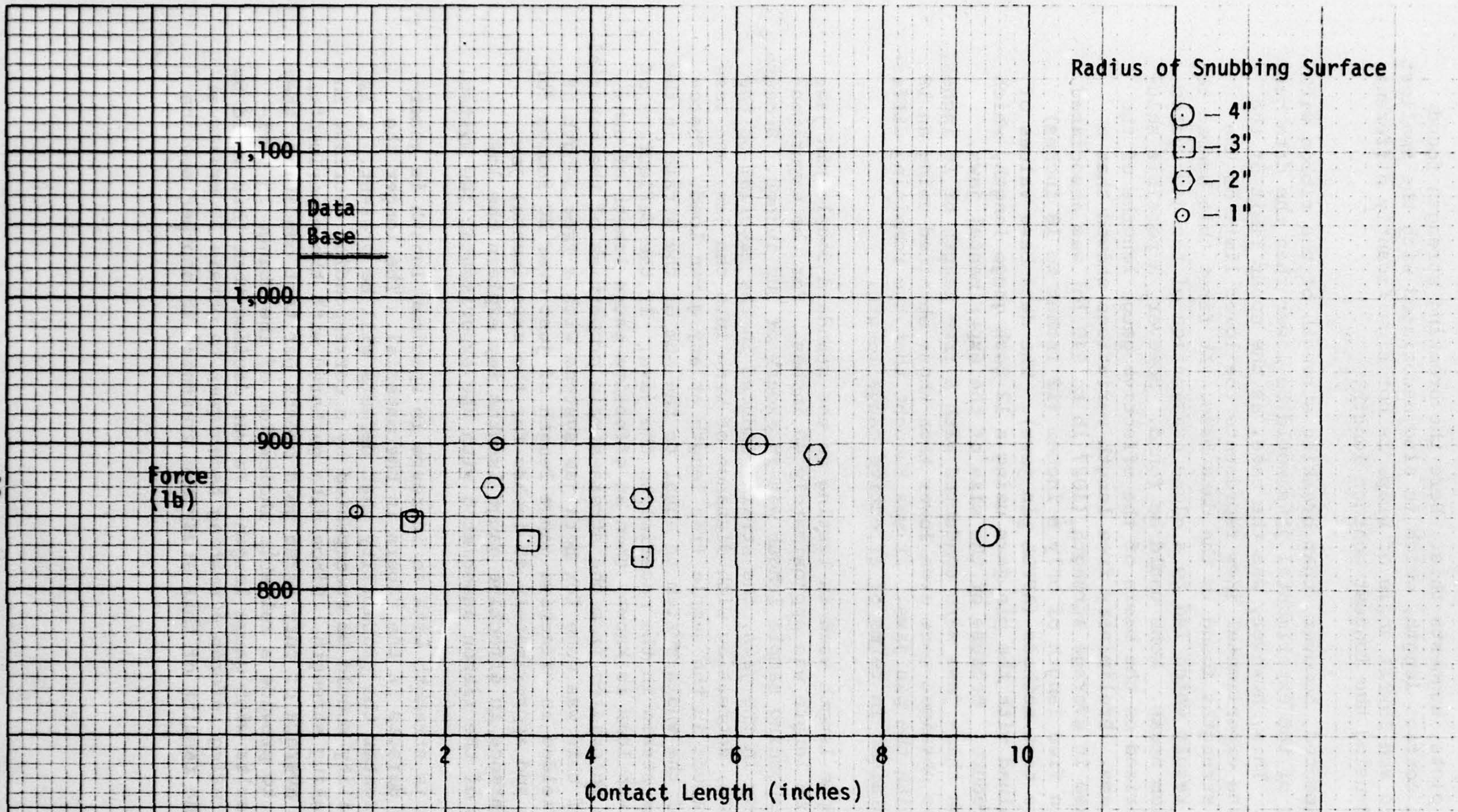


Figure 8. Breaking Strength as a Function of Contact Length for a 2 Inch 1,000 lb Kevlar 29 Ribbon Tested with the Experimental Jaws

and angle of wrap plots, suggests this. Here the breaking strength found using the shortest contact length, which is also associated with the smallest radius of curvature and lowest angle of wrap, is not significantly different from data gathered using the longest contact length.

It was not expected, however, that breaking strength of the ribbon with all configurations of the experimental jaws would be lower than the data base breaking strength. This, however, was the case, as the upper limit of the range found with the experimental jaws represents the lower limit of the range of breaking strengths found in the data base. At first this seemed to be a very curious result which led to a close examination of the jaw system for possible problem areas. None could be found. However, a possible solution was then theorized on the basis of the effective gauge lengths of the different jaw systems. Preliminary free length variations showed that a significant decrease in average strength (1027 lb to 940 lb) was associated with an increase in free length of only 6 inches (12 inches to 18 inches) using the reference test methods (AFFDL pin jaws). The data base values of strength were obtained with the pin jaws using a 12 inch gauge length, which is the normal procedure. Because of the size of the experimental jaws, however, tests with these jaws were conducted with a free length of 18 inches. The strength values obtained were even lower than those obtained using an 18 inch free length with the pin jaws. It was thought that the remaining differences might be explained in terms of effective gauge length.

The total sample length used in testing on the standard double pin jaws with an 18 inch free length was approximately 40 inches. For the experimental jaws the corresponding sample length was in excess of 100 inches. Because of the tension decay in the jaws, the strains induced in the material on the jaw must be variable, decreasing with distance of wrap into the jaw, and less than the strain present in the sample free length at any given load. Therefore, the strain of the whole system is equal to the sum of the strain in the free length and the strain in the material on the jaws. If the deflection of the system at a given load is known, then an effective gauge length of uniform strain can be calculated from the stress-strain properties of the material. An approximation of this was done for both jaw systems with a free length of 18 inches. This yielded an effective gauge length of just over 20 inches for the AFFDL pin jaws and approximately 40 inches for the experimental jaw system. This difference in effective gauge lengths may explain the low values of strength of the ribbon associated with the experimental jaw system.

This decrease in strength with an increase in specimen length is generally attributed to defects in the fibers in the material. The longer the specimen is, the greater the probability that defects will be present. This increase in probability should be accompanied by a corresponding decrease in variability of breaking strength. Since data gathered with the experimental jaws represents an average of only three good breaks per test condition, they are not sufficient to provide a reliable indication of the change in variability of test results with gauge length. It was decided that this would be studied separately using reference testing techniques to obtain 10 breaks at each condition. The results of this study are presented in another section of this report.

Regardless of the reasons for the loss in strength due to increasing the specimen free length, the 2 inch 1,000 lb ribbon seemed unaffected by radius of curvature and angle of wrap. It appeared that the AFFDL pin jaw gave better results than a variable radius and coefficient of friction jaw would give. In light of what had been seen in this test series, it seemed more likely that variations in double pin jaw design would bring more promising results.

D. 1-1/8 Inch 13,500 Lb Webbing

Data gathered with the experimental jaws and the webbing is presented in Table 3. Figures 9 and 10 present breaking strength as a function of radius of curvature of the snubbing surface, angle of wrap, and length of contact with the snubbing surface for the webbing. The majority of these plots showed an expected variation. An increase in breaking strength accompanied increases in drum radius and angle of wrap. Furthermore, unlike the ribbon, most of the test conditions yielded higher values of average breaking strength than were obtained using standard test methods and a free length of 12 inches. However, an anomaly exists with the 4 inch diameter drum at a wrap angle of 45°. As is evident from the plots, values of breaking strength at this condition are not significantly different from values obtained using the highest angle of wrap and largest drum diameter. Investigation of the test configuration yielded nothing unique to this configuration. Repeat of testing gave values which were not significantly different from those obtained in the initial test series. This anomaly appears to be real but the reasons for it are not understood. For this reason it did not seem practical to design a jaw system based on this condition. It did, however, lead to a test variation which was not included among the original test variations. With the 4 inch diameter drum and split capstan installed in the test fixture in a 180° wrap angle configuration, a double pin jaw with 4 inch diameter pins could be simulated. Testing with this double pin wrapping technique yielded values for 2 breaks (15,200 lb and 15,100 lb) which were significantly higher than those obtained with a standard 180° wrap on a 4 inch diameter drum. Also these values were not significantly different from the highest values obtained using any test configuration. These test results, coupled with the superior performance of the AFFDL pin jaws in ribbon testing, led to the decision that double pin jaws should be investigated for webbings as well as ribbons.

E. Conclusions

Performance of the variable radius, angle of wrap experimental jaws was satisfactory in this test series. Testing of the 2 inch wide, 1,000 lb ribbon showed little dependence of breaking strength on either radius of snubbing surface or angle of wrap. Furthermore, overall low breaking strengths in the experimental study relative to the data base are believed to be related to a change in effective gauge length from one jaw system to the other. Testing of the 1-1/8 inch wide 13,500 lb webbing showed an overall expected dependence of breaking strength on radius of snubbing surface and on angle of wrap. However, preliminary tests with a double pin wrapping configuration yielded strengths equal to the highest attained with the experimental jaw setup. For these reasons, a more detailed study of double pin jaw design was warranted.

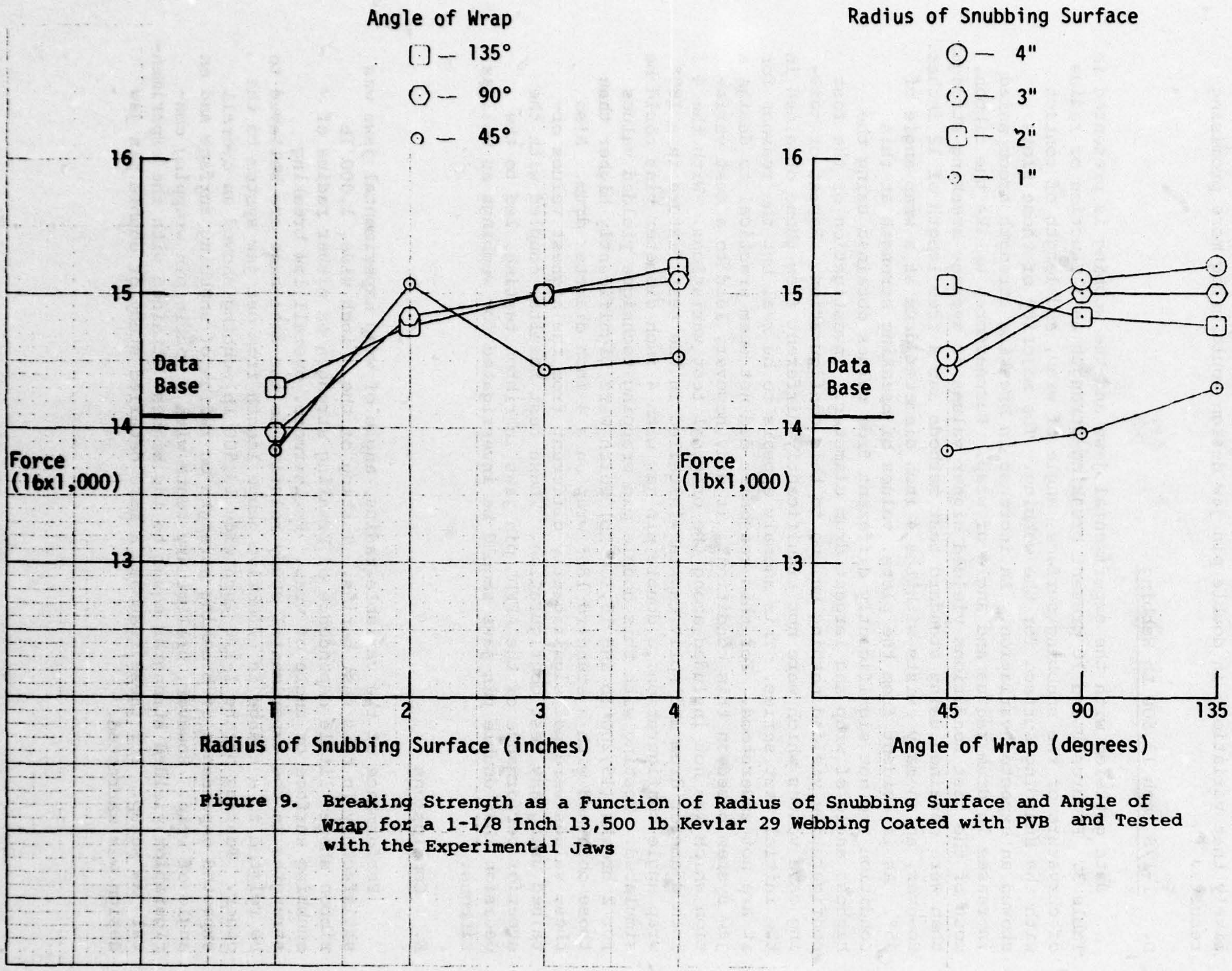


Figure 9. Breaking Strength as a Function of Radius of Snubbing Surface and Angle of Wrap for a 1-1/8 Inch 13,500 lb Kevlar 29 Webbing Coated with PVB and Tested with the Experimental Jaws

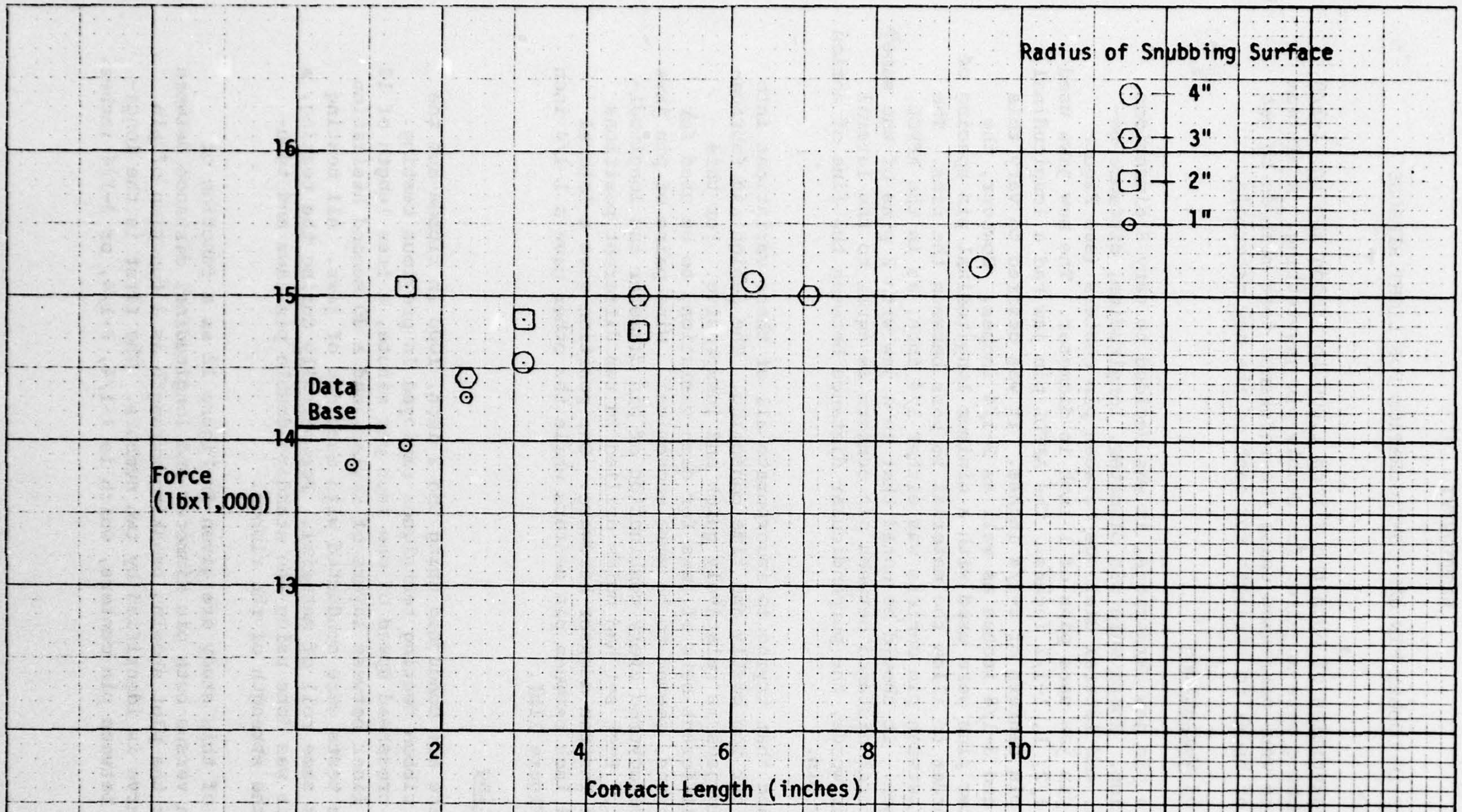


Figure 10. Breaking Strength as a Function of Contact Length for a 1-1/8 Inch 13,500 lb Kevlar 29 Webbing Coated with PVB and Tested with the Experimental Jaws

SECTION VI

VARIATIONS IN DOUBLE PIN JAW CONFIGURATION FOR LIGHT RIBBONS

Additional quantities of both the 2 inch 1,000 lb ribbon and the 1-1/8 inch 13,500 lb webbing were acquired for double pin jaw testing. A minimum of 10 tensile tests were performed using the reference test methods to get an average value of breaking strength for each of the new materials.

A. Explanation of Variations

In the double pin jaw variations, it was decided to vary 3 dimensions in the configuration. These were pin diameter, longitudinal distance between pin centers, and lateral distance between pin centers (see Figure 11a). The AFFDL pin jaw uses pins of 1 inch in diameter. The new jaws used pin diameters of 1/2, 1, 1-1/2 inches. The AFFDL pin jaw had a longitudinal distance between pin centers of 2-1/4 inches. It was desired to vary this to include 1-1/4 and 3-1/4 inches as well as 2-1/4 inches. However, the 1-1/2 inch diameter pins were used with a minimum longitudinal pin spacing of 1-3/4 inches in order to allow the material to pass between the pins. The lateral distance between pin centers was either 1/4 inch, as in the AFFDL pin jaws, or 1 inch. It should be noted that in a jaw with 2 pins of the same diameter, the lateral distance between pin centers is equal to the lateral offset or in other words, the perpendicular distance between the line of action and the secondary pin.

It was decided that trying to incorporate all of these variations into one jaw would be far too costly and time consuming. The design and fabrication of double pin jaws is relatively quick and inexpensive. For this reason building different sets of jaws for each variation, to be used for testing light ribbons, seemed to be more economical. Nine pairs of pin jaws were built. These covered every combination of pin diameter and longitudinal pin placement. Each set had holes drilled in two different positions for attachment of Instron adaptor hardware. One position gave a lateral separation of 1/4 inch between pin centers while the other gave a 1-1/4 inch separation (see Figure 11b).

B. Tensile Testing

The tests were all conducted using the 2 inch, 1000 lb ribbon and the customary Kevlar ribbon testing techniques employed in previous testing. These included a crosshead speed of one inch per minute, a free length of 12 inches, a cotton liner between layers of Kevlar, and a 30 second hesitation at 150 lb. Three tests were conducted with each set of jaws. All testing was done from the same roll of material. Periodically during the testing, a set of three tests was done using the standard double pin jaws and techniques to check the strength of the ribbon.

The results of this study are given in Figure 12 as a function of breaking strength versus both pin diameter and longitudinal distance between pin centers. For the plot showing breaking strength as a function of pin diameter, each curve is identified by two numbers. The first is the longitudinal distance between pin centers, which is 1-1/4, 2-1/4, or 3-1/4 inches.

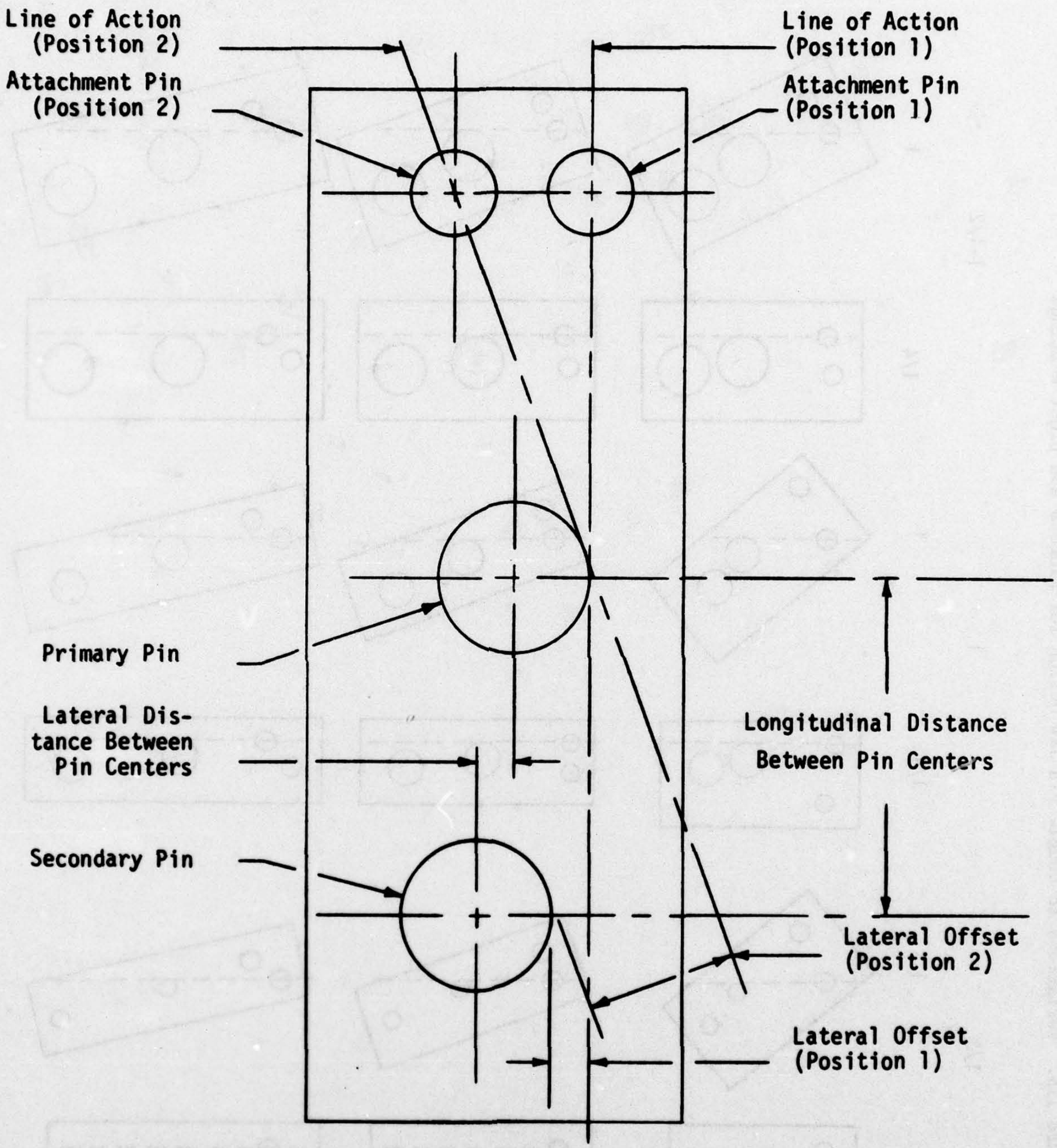
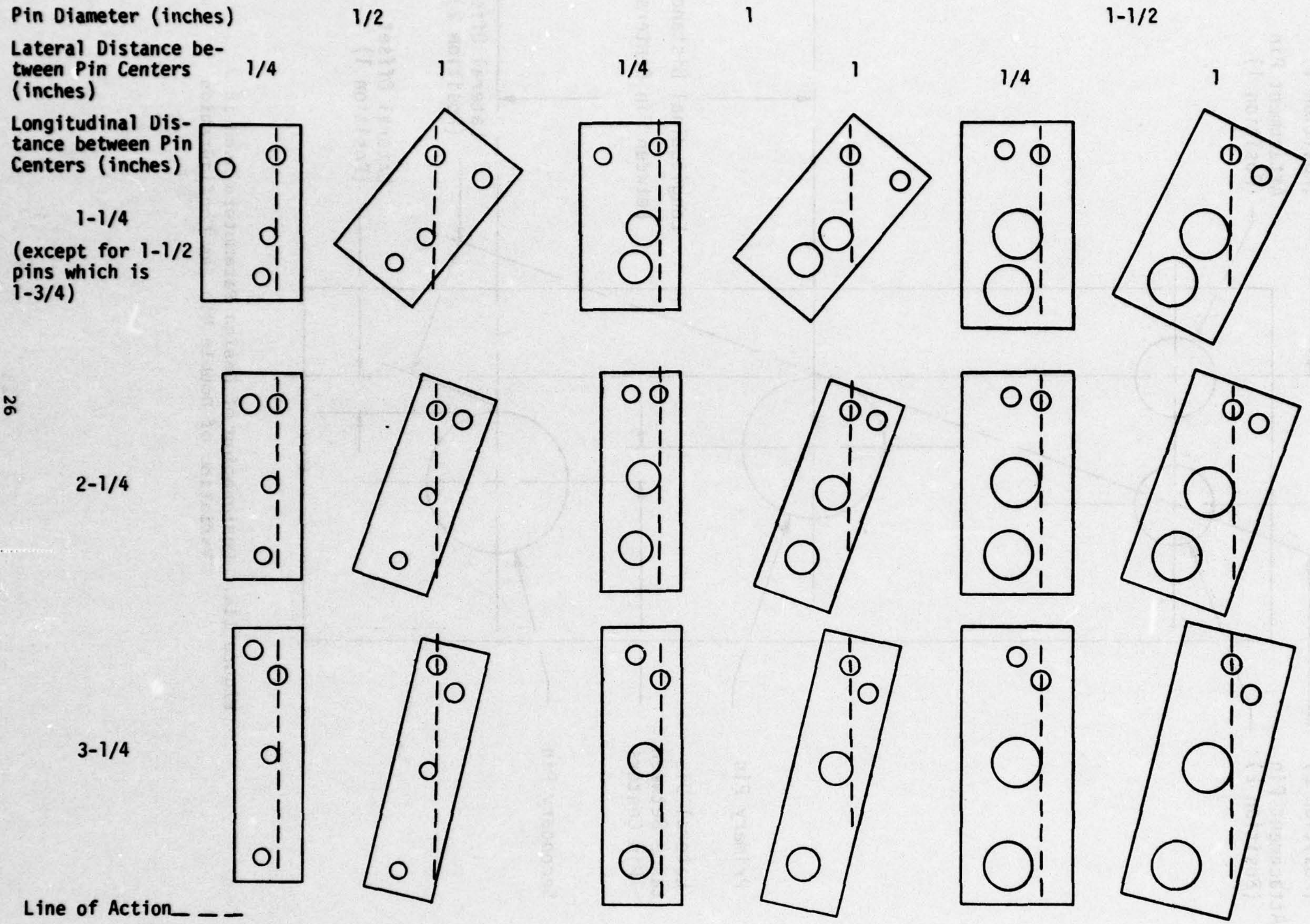


Figure 11a. Designation of Design Parameters used in Variation of Double Pin Jaw Configuration

Figure 11b. Variations in Double Pin Jaw Design for Ribbons and Light Webbings



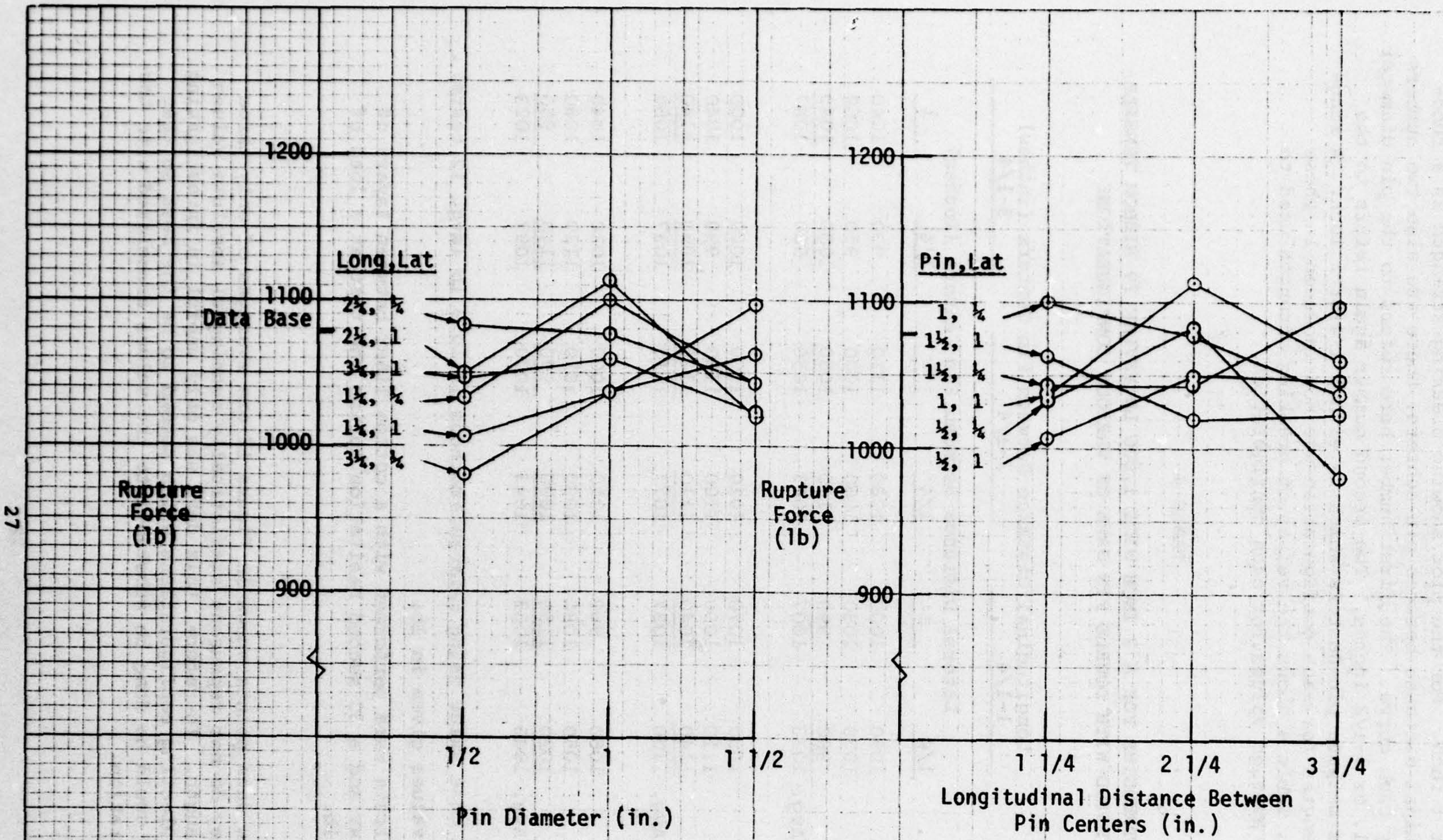


Figure 12. Rupture Force as a Function of Pin Diameter and Longitudinal Distance Between Pin Centers for a 2 Inch Wide 1,000 Lb Kevlar 29 Ribbon Tensile Tested Using Double Pin Jaws of Various Configurations

The second number refers to the lateral distance between pin centers which is either 1/4 or 1 inch. For the plot showing breaking strength as a function of longitudinal distance between pin centers, there are also two numbers used to identify each curve. The first number here refers to the pin diameter of either 1/2, 1, or 1-1/2 inches. The second number again refers to the lateral distance between pin centers which is either 1/4 or 1 inch. A range of breaking strengths for each configuration was not included in these plots. Instead, Table 4 shows the values of breaking strength used to calculate these average values for each configuration.

TABLE 4

BREAKING STRENGTHS FOR A 2 INCH WIDE 1,000 LB KEVLAR 29 RIBBON TENSILE TESTED WITH DOUBLE PIN JAWS OF VARIOUS CONFIGURATIONS

Pin Diameter (inches)		Longitudinal Distance Between Pin Centers (inches) 1-1/4		2-1/4		3-1/4	
		Lateral Distance Between Pin Centers (inches)					
		1/4	1	1/4	1	1/4	1
		1050	1000	1080	1110	990	1040
1/2		1070	1030	1060	1000	950	1060
		980	990	1110	1050	1000	1040
	Avg.	1033	1007	1083	1050	980	1047
		1050	1070	1020	1100	1070	1000
1		1110	1000	1100	1120	990	1040
		1140	1040	1110	1120	1050	1140
	Avg.	1100	1037	1077	1113	1037	1060
1-1/2		1060	960	1010	1000	1030	1040
		1050	1080	1030	1070	1120	1080
		1020	1150	1090	990	1140	950
	Avg.	1043	1063	1043	1020	1097	1023

Notes:
1) Data base value using reference methods is 1078 lb (avg. 12 tests).
2) All values given in lb.
3) All tests were performed with a cotton liner between layers of Kevlar and a 30 second hesitation during the test at a load of 150 lb.

Because the data points shown in Figure 12 are averages of only three good breaks, they do not represent statistically meaningful absolute values of breaking strength. Therefore, this data was only useful in investigating trends and in selecting configurations which seemed to be the best so that further testing could be done to substantiate the values associated with the optimum configuration.

Looking at the first plot, that of breaking strength as a function of increasing pin diameter, there are six curves which show three different trends. The first trend is evident in one of the curves as a negative slope indicating a loss in breaking strength associated with increasing pin diameter. This trend seems unlikely for most Kevlar constructions based on past experience. The second trend is evident in two of the curves as a positive slope indicating an increase in breaking strength associated with increasing pin diameter. This trend seems more likely based on the past experience. The third trend is evident in three of the six curves as a change in slope at the one inch pin diameter giving the curve a concave downward shape. This would seem to indicate that a one inch diameter pin is optimum. Looking to the left of the line representing a one inch pin diameter, an increase in breaking strength with increasing pin diameter from 1/2 inch to 1 inch is evident in five of the six curves. To the right of this line, it can be seen that a decrease in breaking strength is associated with an increase in pin diameter from 1 inch to 1-1/2 inches in four of the six curves. These observations would seem to indicate that the 1 inch pin used in the AFFDL jaws is optimum for testing this Kevlar construction with double pin jaws. However, for reasons mentioned previously, and because of the existence of other trends in this data group, this conclusion cannot be considered definite.

The plot of breaking strength as a function of longitudinal distance between pin centers can be interpreted in a similar manner. In this plot there are four trends present among the six curves. One curve has a negative slope while another shows a positive slope indicating both an increase and decrease in breaking strength with increasing longitudinal distance between pin centers. Also, one curve has a shape which is concave up while the remaining three have a concave down shape. This would indicate both a maximum and a minimum value for breaking strength at a longitudinal distance of 2-1/4 inches between pin centers. Obviously there cannot be increasing and decreasing trends or maximum and minimum values at the same point if indeed all of the breaking strength values are subject to the same trend for all variations. Looking, as before, at the center of the curves, which represents a longitudinal distance of 2-1/4 inches between centers, observations concerning the slope of the curves to either side of this line could indicate which trend is correct. To the left of this line, there is an increase in breaking strength with increasing pin separation evident in three of the six curves. To the right of this line, there is a decrease in breaking strength with increasing pin separation evident in four of the six curves. This observation, coupled with the previous observation that a maximum occurs at a longitudinal distance of 2-1/4 inches between pin centers for half of the curves, would seem to indicate that this configuration is optimum.

This configuration of one inch diameter pins spaced 2-1/4 inches apart from center to center, is the configuration which most closely approximates the AFFDL pin jaw configuration. Looking back at the data presented in Figure 12 it can be seen that this configuration with a 1/4 inch lateral distance between pin centers gave an average breaking strength identical to that obtained with the AFFDL pin jaws. This value ranked fifth out of 18 configurations in terms of highest average breaking strength. Also this same configuration with a 1 inch lateral distance between pin centers yielded the highest average breaking strength of all 18 configurations.

A general look at the values given in Figure 12 shows that most of the variations gave average breaking strengths below that of the data base. However, none of the configurations yielded a loss in strength of more than 10 percent from that found with the AFFDL jaws. Most of the values shown in the figure lie within a few percent of the data base value. This would seem to indicate that the pin jaw configuration is not critical since there is so little change in strength associated with such a wide variation in design. This conclusion was strengthened by retesting those configurations which were thought to be optimum. The three configurations which yielded the highest average breaking strengths were retested to give an average of ten good breaks. The first of these were the jaws with one inch diameter pins and a 2-1/4 inch longitudinal and 1 inch lateral distance between pin centers. The average breaking strength for this configuration dropped from 1113 lb to 1066 lb after additional testing. The next jaw system tested also had one inch diameter pins but had a 1-1/4 inch longitudinal and 1/4 inch lateral distance between them. Its value of average breaking strength for the ribbon dropped from 1100 lb after three tests to 1058 lb after ten tests. The third configuration had 1-1/2 inch diameter pins with a 3-1/4 inch longitudinal and 1/4 inch lateral distance between pin centers. Its value of average breaking strength for the ribbon dropped from 1097 lb after three breaks to 1074 lb after ten breaks. These new values for breaking strength fall just below the data base value. This not only indicates that pin jaw design is less critical than it was originally thought to be but also that the AFFDL jaw could be marginally better than any configuration used so far for testing this material. It should be mentioned at this point that the values determined during this testing apply only to the 2 inch 1000 lb ribbon. Even though it is expected that the trends discovered here will be applicable to other Kevlar constructions, further testing will be necessary to substantiate this.

SECTION VII

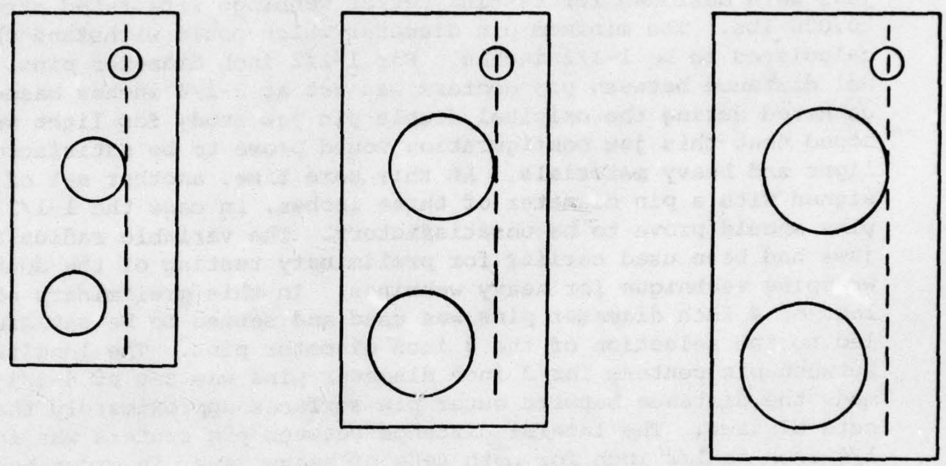
VARIATION IN DOUBLE PIN JAW CONFIGURATION FOR HEAVY WEBBING

A. Explanation of Variations and Testing

The double pin jaw design study for light materials led to the design of several pairs of double pin jaws for use with heavy Kevlar webbings. The jaws were designed for testing Kevlar webbings with rated strengths up to 20,000 lbs. The minimum pin diameter which could withstand these loads was calculated to be 1-1/2 inches. For 1-1/2 inch diameter pins, the longitudinal distance between pin centers was set at 3-1/4 inches based on data gathered during the original double pin jaw study for light webbings. It was hoped that this jaw configuration would prove to be satisfactory for both light and heavy materials. At this same time, another set of jaws was designed with a pin diameter of three inches, in case the 1-1/2 inch diameter pins should prove to be unsatisfactory. The variable radius/angle of wrap jaws had been used earlier for preliminary testing of the double pin jaw wrapping technique for heavy webbings. In this preliminary study, the equivalent of 4 inch diameter pins was used and seemed to be satisfactory. This led to the selection of the 3 inch diameter pins. The longitudinal distance between pin centers for 3 inch diameter pins was set at 4-3/4 inches. This made the distance between outer pin surfaces approximately the same for both sets of jaws. The lateral distance between pin centers was increased from 1/4 inch to 1/2 inch for both sets of heavy jaws, in order better to accommodate the thicker materials (see Figure 13).

The 1-1/8 inch 13,500 lb Kevlar webbing received for pin jaw testing was used to test these jaws. Table 5 gives the results of this testing in addition to data base values for this material. The 1-1/2 inch pins proved to be unsatisfactory for this webbing. All four tests conducted showed a sudden load drop at 11,000 to 13,000 lb due to a sudden slip of the material in the jaw. This meant that there was insufficient contact length for tension decay but it did not mean that the smaller radius of curvature would give lower values of breaking strength. However, the 3 inch diameter pins were capable of holding the specimen to break. As Table 5 shows, the values for breaking strength were slightly higher than those found using standard methods. It should be mentioned that because of the size of the jaws, it was necessary to use a 16 inch specimen free length instead of the standard 12 inch specimen free length. The total specimen length was about 60 inches as compared to about 50 inches for the standard 4 inch diameter split capstans. One of the most obvious advantages of this jaw system over the standard split capstans was the total absence of cutting and bad breaks. The 14 values of breaking strength found with the split capstans represent the usable information gathered from 25 tensile tests. Eleven of these tests ended with the specimen being cut at the back of the jaw where the tail of the specimen exits from between the capstan halves and bends around the capstan under the outer wrap. This cutting has been a problem with the 1-1/8 inch 13,500 lb webbing particularly when it has been coated with PVB. Problems such as this can cause a substantial loss of both time and material. The double pin jaws completely eliminated this, every specimen tested producing an acceptable break.

Pin Diameter	1-1/2	2-1/2	3
Longitudinal Distance Between Pin Centers	3-1/4	4-1/4	4-3/4
Lateral Distance Between Pin Centers	1/2	1/2	1/2



Line of Action — — —

Figure 13. Variations in Double Pin Jaw Design for Heavy Webbings

TABLE 5

VALUES OF BREAKING STRENGTH FOR A 1-1/8 INCH 13,500 LB KEVLAR 29 WEBBING TESTED WITH THREE DIFFERENT DOUBLE PIN JAW CONFIGURATIONS

Jaw Configuration (inch)					
Pin Diameter	1-1/2	2-1/2	3		
Longitudinal distance between pin centers	3-1/4	4-1/4	4-3/4		
Lateral distance between pin centers	1/2	1/2	1/2	Standard 4 inch split capstan	
	11,100*	15,300	15,800	14,900	14,700
	12,100*	14,700	15,600	14,600	14,700
	12,900*	14,800	15,100	14,400	13,900
	11,500*	15,100	14,900	14,600	15,200
		14,700*	15,100	14,400	14,900
		14,000*	14,900	14,500	15,400
				15,400	14,100
Average		14,975	15,400	14,700	

*Test specimen slipped in jaw and did not break.
All values in lb.

After determining that a 3 inch diameter pin was adequate, a third set of jaws was designed with 2-1/2 inch diameter pins. In order to keep the distance between pin surfaces constant, the longitudinal distance between pin centers was set at 4-1/4 inches for this jaw system. The lateral distance between pin centers was also kept constant for the heavy jaws at 1/2 inch. It was hoped that some weight savings could be realized with this jaw over the 3 inch diameter pin jaws.

A total of 6 tensile tests was run with these jaws using the 1-1/8 inch 13,500 lb Kevlar webbing as the test sample. These tests are also presented in Table 5. The average value for breaking strength calculated from the first 4 of these 6 tensile tests lies approximately midway between the average values determined with the standard capstans and the 3 inch diameter pin jaws. The remaining two tests ended with a slip at approximately 14,000 to 15,000 lbs. This indicated that these jaws will not have the desired capacity of 20,000 lbs, due to insufficient contact length for tension decay.

The double pin jaws with the 3 inch diameter pins were the only jaws which seemed to be satisfactory in most areas. However, the size of the jaws made them very heavy and difficult to use. It was also impossible to use a 12 inch specimen free length. For these reasons, two more sets of jaws were built, each with two different diameter pins. In each jaw, the primary pin, which makes initial contact with the specimen free length, was 3 inches in diameter. The secondary pin was 1-1/2 inches in diameter for each jaw. The lateral offset was still 1/2 inch, as in the case of the jaws which had two pins of the same diameter. The two sets of jaws differed only in longitudinal distance between pin centers. This distance was 3 inches for one set of jaws and 4 inches for the other set (see, for example, Figure 14).

B. Selection of Optimum Jaw Configuration

The 1-1/8 inch 13,500 lb webbing was used initially to test these jaws. The results of these tests are given in Table 6. The jaws with the 4 inch longitudinal distance between pin centers gave a higher average value of breaking strength with lower variability than the jaws with a 3 inch separation.

Both sets of jaws were then tested for ultimate clamping capacity. A 1-3/4 inch 20,000 lb webbing was used for this purpose. Both sets of jaws held the webbing to rupture well above the required 20,000 lb capacity. The webbing ruptured at a load of 24,000 lb using the jaws with a 4 inch separation and at a load of 23,750 lb using the jaws with a 3 inch separation.

The jaws were then tested with the 2 inch 1,000 lb ribbon which had been acquired for pin jaw testing. This data is also presented in Table 6 along with data from tests done at the same time using standard test methods. In this case the average value of breaking strength found using the jaws with the 4 inch separation was the highest but the variability in this data was also the highest. These tests were then repeated with a different roll of the 2 inch 1,000 lb ribbon. This time the average values of breaking strength and coefficient of variation were essentially the same for the two new jaw systems. However, the jaws with the 4 inch separation did yield a slightly higher value of breaking strength and lower variability than the jaws with the 3 inch separation. Moreover, the values obtained with these jaws were the same as those for the standard double pin jaws.

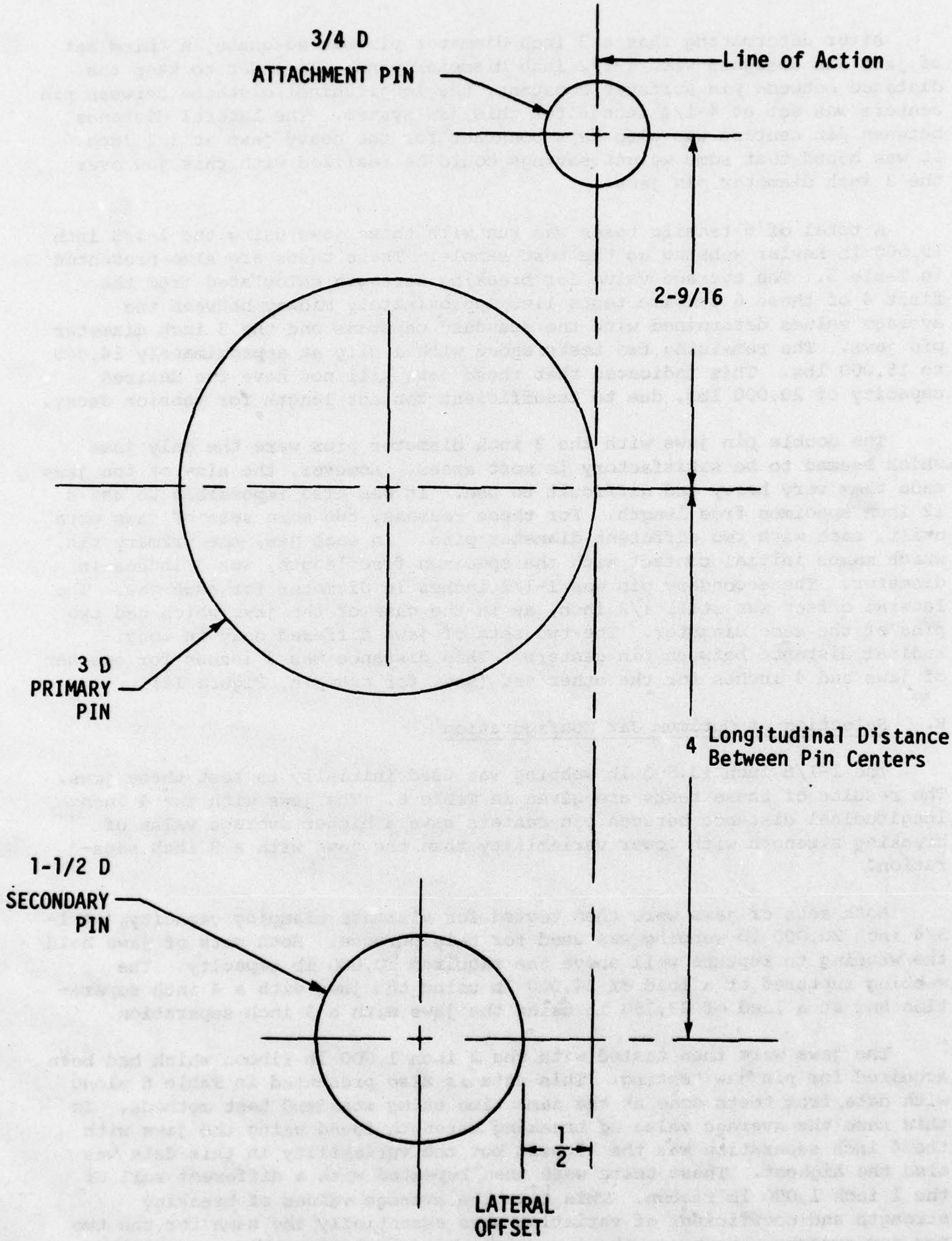


Figure 14. Optimum Double Pin Jaw Configuration

TABLE 6

TENSILE TESTING KEVLAR 29 STRUCTURES USING TWO DIFFERENT SETS OF DOUBLE PIN JAWS FOR COMPARISON PURPOSES IN SELECTION OF THE OPTIMUM JAW CONFIGURATION

Material	1-1/8" 13,500 lb Webbing Coated Roll G&I	2" 1000 lb Ribbon Roll A	2" 1,000 lb Ribbon Roll B	1" 6,000 lb Webbing	1/2" 250 lb Light Webbing	1-3/4" 20,000 lb Webbing Coated
Jaw Configuration						
3" Primary Pin	15,300		1,050	6,200	339	
1-1/2" Secondary Pin	15,900	1,000	1,020	6,200	318	24,000
4" long; 1/2" lat.	15,700	960	1,030	6,150	325	
	15,200	970	990	6,250	330	
	14,600	990	1,020	6,250	325	
	14,900	1,030				
Average	15,270	990	1,022	6,210	327	
S.D.	484	27	22	42	8	
C.V. (%)	3.2	2.8	2.1	0.7	2.4	
3" Primary Pin	15,500	960	970	6,200	342	
1-1/2" Secondary Pin	15,600	950	1,000	6,100	338	23,750
3" Long	15,500	950	1,010	6,250	360	
1/2" Lat.	14,200	940	1,050	6,150	355	
	14,500	960	1,030	5,950	355	
	14,600					
Average	14,980	952	1,012	6,130	350	
S.D.	617	8	30	115	9	
C.V. (%)	4.1	0.9	3.0	1.9	2.7	
Reference Methods		1,000	1,050			
		980	1,050	Data	Data	
		980	950	Base	Base	
		1,000	1,000	Values[1]	Values[1]	
		950	1,010			
Average		982	1,012	5,975	345	
S.D.		20	41	250	6	
C.V. (%)		2.1	4.1	4.2	1.8	

1. See Table 2.

All values in lb.

Crosshead speed for all tests was 1 inch per minute.

As a final check, both sets of jaws were tested with a 1 inch 6,000 lb webbing and a 1/2 inch 250 lb light webbing. This data is also presented in Table 6. Again the jaws with the 4 inch separation yielded a higher average value of breaking strength with less variability in the case of the 1 inch 6,000 lb webbing. However in testing the 1/2 inch 250 lb light webbing, the jaws with the 3 inch pin separation yielded a higher average value of breaking strength with lower variability than the jaws with a 4 inch pin separation. This is a reversal of the trend seen so far in testing with these jaws.

Overall the jaws with the 4 inch longitudinal distance between pin centers performed the best in this test series. Average rupture strengths were generally higher with low variation in test results using this jaw system. A slight weight and size savings could be realized with the double pin jaws having the 3 inch separation. However, the superior performance of the larger jaws outweighed any advantages gained by using the smaller jaws. Figure 14 shows the configuration of the double pin jaws selected as optimum for tensile testing Kevlar narrow fabrics.

SECTION VIII

VARIATION IN TENSILE TESTING TECHNIQUES

A. Test Speed

All tests were performed on an Instron tensile testing machine. Tensile testing in this machine is performed by holding the upper jaw stationary and moving the crosshead and lower jaw downward, thus increasing the distance between them. The machine can be preset to move the lower jaw at speeds between 0.02 and 2 inches per minute for all of the materials being considered in this program. Several crosshead speeds were investigated using the 2 inch 1,000 lb ribbon and the 1-1/8 inch 13,500 lb webbing as test samples. The crosshead speed which has been used in all previous testing, including generation of data base values, is one inch per minute. Because these studies were scattered throughout the course of the work, some were done using AFFDL pin jaws and some using the variable radius/angle of wrap experimental jaw. The type of jaw used is identified in each case. Three tests were performed with each material at crosshead speeds of 0.5 and 2 inches per minute using reference test methods and AFFDL pin jaws. Table 7 shows the results of this test series. When compared to the data base, the 1-1/8 inch 13,500 lb webbing, representing the heavy materials, showed a significant strength loss associated with a change in crosshead speed from the standard one inch per minute. However, the ribbon exhibited only a slight decrease in rupture strength with an increase in crosshead speed from one to two inches per minute. The slower speed of 0.5 inches per minute did cause a significant loss in rupture strength for the ribbon. Therefore the standard crosshead speed of one inch per minute will remain as the standard testing speed for Kevlar fabric.

TABLE 7

BREAKING STRENGTH VALUES FOR TWO DIFFERENT KEVLAR 29 STRUCTURES TESTED AT TWO DIFFERENT CROSSHEAD SPEEDS USING REFERENCE TEST METHODS (AFFDL Pin Jaws)

		Crosshead Speed (inches/minute) 0.5	2
1-1/8 inch 13,500 lb Kevlar 29 Webbing Coated with PVB		13,300	14,000
		13,200	13,300
		13,200	12,900
	Average	13,230	13,400
2 inch, 1,000 lb Kevlar 29 Ribbon		960	1,010
		1,000	970
		980	1,080
	Average	980	1,020

All values in lb.

B. Specimen Free Length

Specimen free length is defined as the unsupported length of specimen with no tension on the sample or the distance between tangent points of the line of action with the initial snubbing surface or pin of each jaw. The standard specimen free length is 12 inches. In order to check whether changes in this free length would affect the measured strength, a preliminary check was run using both the ribbon and the webbing. Three tests were performed, using the ribbon and webbing as test samples and reference test methods with AFFDL pin jaws, with the specimen free length increased to 18 inches. With both materials, a significant strength loss was found with this increase as compared to data base values. The first column of Table 8 shows the results of this testing.

TABLE 8

BREAKING STRENGTH VALUES FOR TWO DIFFERENT KEVLAR 29 STRUCTURES
TENSILE TESTED WITH VARIOUS SPECIMEN FREE LENGTHS
USING REFERENCE TEST METHODS

		Preliminary Check AFFDL Pin Jaws	AFFDL Pin Jaws Specimen Free Length (inches)			
		18	12	18	24	36
2 Inch 1,000 lb		930	920	900	890	930
Kevlar 29 Ribbon		950	930	970	910	930
Data base average		940	900	910	910	870
1027 lb	Avg	940	1000	960	880	850
			980	960	910	850
			930	910	930	850
			930	960	930	870
			950	960	880	730
			930	970	990	880
			970	980	960	940
	Average		944	948	919	870
	S.D.		31	29	35	61
	C.V. (%)		3.2	3.0	3.8	7.0
1-1/8 Inch 13,500 lb		13,200				
Kevlar 29 Webbing		14,000				
Coated with PVB		13,400				
Data base average						
14,090 lb		13,533				

All values in lb.

In conjunction with the work done with variable radius/angle of wrap jaws, a more detailed study of rupture strength and variability as a function of specimen free length was performed with the ribbon. Specimen free lengths of 12, 18, 24, 36 inches were investigated using the AFFDL pin jaws. Ten tests were performed with each free length in order to get a good value of rupture strength and variability. It was hoped that this test series would explain the low values of breaking strength found for the ribbon using the variable radius/angle of wrap jaws.

Table 8 shows the results of this test series. The decrease in strength due to an increase in specimen free length was not as great as anticipated. An increase in the free length of 200% (from 12 to 36 inches) yielded a decrease in breaking strength of less than 10%. The effect of increasing gauge length on the strength of Kevlar fabrics is confirmed, however, in a study of high altitude balloon fabrics carried out by Martin Marietta.[7]

Also, the coefficient of variation ranged from 3% to about 7% with the longest free length showing the greatest variability. Although one would expect variability to decrease with increasing free length, there could be some frequency of defects which happens to more severely affect the variability of breaking strength associated with longer free lengths. Since the ratio of free length to total specimen length increases with increasing free length, the probability of a defect occurring in the specimen free length is much greater for the longer free length. However, if the frequency of defects is very low (several specimen lengths between defects) it would mean that the variability should be higher in the longer free lengths.

C. Liner Material

As part of the standard procedure for testing lightweight Kevlar fabrics with the AFFDL pin jaws, a liner material is inserted between layers of Kevlar on the primary pin of each jaw. This technique was employed in an attempt to avoid bad breaks which were a problem with the wide ribbons in particular. Originally a fairly heavy cotton duck of unknown construction was used for all in-house testing. One of the objectives of this program was to determine if a liner was necessary and, if so, to find a material and construction which would be adequate for testing purposes and suitable for inclusion into military specifications. A material used for making pockets for clothing (cloth, silesia, cotton, MIL-C-326) was acquired for these reasons. It was found that a double thickness of this material performed as well as the original cotton duck. Because this new material is a tighter weave than the duck, it withstands the stresses better than the duck with less skewing of yarns and is very reusable.

Originally the liner material was used for all testing done with the AFFDL pin jaws. This meant that all structures up to 5,000 lb rated strength were tested with a liner material. In order to determine what fabrics required a liner material, several structures were tested with and without a liner using the optimized jaw design (see Figure 14). The results of this testing are presented in Table 9. The first structure tested was the 2 inch 1,000 lb ribbon. Five tests were conducted using reference methods and five tests were run using the hesitation technique without a cotton liner. The average values of breaking strength found with each technique were about equal. However, of the five tests conducted without the liner, two of them were considered tears and were not included in the average value. This indicates that a liner material serves only to help prevent poor breaks, but does not have a significant effect on breaking strength values when good breaks are possible without a liner.

An identical test series was run using the 1 inch 1,000 lb webbing as a test sample in the optimized jaws. In this test series, a slightly higher average value of breaking strength was found without a liner. However, the variability in the data was lower for the tests conducted with a liner. Variability in data generated from tests without a liner was still very low and the improvement in variability when a liner is used is small.

TABLE 9

BREAKING STRENGTH VALUES FOR SEVERAL DIFFERENT KEVLAR 29 STRUCTURES TENSILE TESTED WITH AND WITHOUT LINER (CLOTH, SILESIA, COTTON, MIL-C-326) USING OPTIMUM JAW CONFIGURATION (Ref. Figure 14)

		2 Inch 1,000 lb Kevlar 29 Ribbon 500 lb/in.	1 Inch 1,000 lb Kevlar 29 Webbing 1000 lb/in.	2 Inch 2,000 lb Kevlar 29 Ribbon 1000 lb/in.	1-3/4 Inch 1,200 lb Kevlar 29 Ribbon 685 lb/in.	3/4 Inch 500 lb Kevlar 29 Ribbon 666 lb/in.
With Liner		880	1,140	2,350*		
		940	1,170	2,900		
		910	1,170	2,850	1,200*	555
		880	1,180	2,450*	1,100*	580
		920	1,160	2,400*	1,210*	570
	Average	906	1,164	2,590	1,170	568
	S.D.	26	15			
	C.V. (%)	2.9	1.3			
Without Liner		950	1,150			
		870*	1,200			
		900	1,200	2,400*	1,160*	550
		820*	1,220	2,625*	1,290*	530
		890	1,180	2,600*	1,240*	560
	Average	913	1,190	2,541	1,230	546
	S.D.	32	26			
	C.V.	3.5	2.2			
		(Average of 3 tests)				

*Specimen ruptured by tearing.

All values in lb.

Crosshead speed for all tests was 1 inch per minute.

Three other structures which are not included in the test methods program were used to gain more confidence in the use of a liner material in the optimized jaws. A minimum of three tests was conducted with and without a liner for each material. The first material used was a 2 inch 2,000 lb ribbon. Five breaks were performed with a liner. Three of these tests ended with edge breaks which were considered bad. However, three tests conducted without a liner also ended with edge breaks. Average values of breaking strength were similar but slightly higher for tests conducted with a liner material. The next material tested was also subject to poor breaks. This was a 1-3/4 inch 1,200 lb ribbon. All tests ended with the specimen tearing in the free length. This time, however, the average value of breaking strength found without the use of a liner, was slightly higher than the value found with a liner. The final material to be tested was a 3/4 inch 500 lb ribbon. All breaks in this test series were good. The average value of breaking strength found with the liner was slightly higher than the value found without the liner. In most cases, variability seemed about the same for data gathered with and without a liner between layers of Kevlar. It is probable that the unsatisfactory breaks reflected a deficiency in the materials themselves, and not in the test procedure. At any rate, except for the 2 inch 1000 lb ribbon, there is no indication that the use of the liner has alleviated the problem.

The results of this investigation indicate that a liner material is not necessary for testing Kevlar constructions with rated strengths above 500 lb/inch. These results also indicate that use of a liner material with constructions having rated strengths between 500 and 1,000 lb/inch will not cause a serious loss in breaking strength and could help reduce variability of results and prevent bad breaks. However, use of a liner material is not recommended for materials in this range of strengths unless problems arise in testing. This is because alignment of the material in the jaw is more difficult with the liner inserted because the inner wrap is not visible. A misalignment in the jaw can cause an unequal length effect which could result in a tearing of the specimen. Use of the liner material with constructions of rated strengths above 1,000 lb should also be avoided unless problems arise in testing. It is not expected that any effect would be seen from use of a liner with constructions in this range except possibly for wide materials (approximately 2 inches).

When using a cotton liner for testing, several procedures should be followed. The material should be cut so that a double layer 2-1/8 inches wide and 10 inches long can be used. The double layers should be in exact alignment with one another with no folds or wrinkles on the pin, in order to avoid variations in thickness. The liner should be centered on the pin both circumferentially and across its width (see Figure 16). If the liner is not laid symmetrically around the circumference of the pin, the end of the liner could be pulled between the layers of Kevlar and cause an inconsistency in the outer wrap. Similarly the liner, which is wider than the separation between side plates on the jaw, should be allowed to curl against the side plates an equal amount on each edge, especially for 2 inch wide Kevlar constructions. This will help insure that variation in liner thickness is kept to a minimum. For less wide materials a more difficult task is alignment of the inner and outer wraps directly on top of each other and centered on the pin. This can sometimes be done by lifting the outer wrap and liner together to check the inner wrap before applying tension. However, after all slack has been taken out of the sample, this can no longer be done. Checking must then be done by feeling for a lump to one side of the outer wrap underneath

the liner which would indicate that the inner wrap slipped to one side as the slack was pulled through the jaw. Sometimes the liner may be pulled back to the edge of the outer wrap to see if the inner wrap is protruding. Regardless of what techniques are used to ensure proper alignment, it is extremely important to attain exact alignment or bad breaks could occur.

D. Pre-tensioning

One aspect of the procedures used for testing all materials with the AFFDL pin jaws was to stop the test at approximately 15% of the rated strength for 30 seconds. This technique was believed to allow equalization of warp yarn tensions and help to prevent bad breaks. An investigation of this technique was carried out using the optimized jaw design in an attempt to determine the necessity of this procedure. Table 10 shows the results of this investigation. The 2 inch 1,000 lb ribbon was the first material used to check this technique. Five tests were performed with and without the hesitation. The cotton liner was used for all testing. A significant increase in breaking strength was realized when hesitation was not used. Although the coefficient of variation was much lower when hesitation was used, variability when hesitation was not used was still very good. The hesitation was therefore considered unnecessary for testing this material. To substantiate this, the 2 inch 500 lb ribbon was tested in the same manner. This material showed an insignificant loss in strength when no hesitation was used and, in this case, the coefficient of variation was essentially equal for data gathered by both methods.

TABLE 10

BREAKING STRENGTH VALUES FOR TWO DIFFERENT KEVLAR 29 STRUCTURES TENSILE TESTED WITH AND WITHOUT HESITATION AT 15% OF RATED LOAD DURING TESTS USING OPTIMUM JAW CONFIGURATION

		2 Inch 1,000 Lb Kevlar 29 Ribbon	2 Inch 500 Lb Kevlar 29 Ribbon
With Hesitation		900	400
		900	390
		910	420
		910	440
		910	425
	Average	906	415
	S.D.	5	20
	C.V. (%)	0.6	4.8
Without Hesitation		990	435
		940	410
		970	390
		960	425
		950	390
	Average	902	410
	S.D.	19	20
	C.V. (%)	2.0	5.0

All values in lb.

Crosshead speed for all tests was 1 inch per minute.

This series has shown that there is no increase in breaking strength associated with use of the hesitation technique when tensile testing Kevlar woven fabrics with optimized double pin jaws. However, there could possibly be a slight decrease in variation of data associated with the use of this technique. It is recommended that this technique not be used except when problems arise with bad breaks or high variability of results. Even in these situations, the advantages of using this technique are questionable.

E. S-Type Specimen Wrap

Many testing labs and production weaving facilities use an S-type specimen wrapping configuration. The S-type specimen wrap is attained by turning one jaw around so that the jaws are positioned with one jaw on each side of the specimen free length. The rationale for this was that without it, the same side of the specimen would contact the surface of the jaw and would follow a slightly smaller radius of curvature on both jaws than the other side of the specimen. This was believed to cause an uneven length effect in the warp. However, if the warp yarns in the material weave from one surface of the specimen to the other, then all of the warp yarns must see the same length and none of them follow the smaller radius of curvature exclusively. All of the Kevlar constructions in this program are of this type including the double layer heavy webbings. Also, the double pin jaw and wrapping technique is unique in that there is a reversing or S-type wrap within the jaw itself. Therefore the inner specimen surface as wrapped around the primary pin of the inner wrap becomes the outer specimen surface on the outer wrap around the primary pin. For these reasons, it was felt that this technique was probably not necessary.

Several tests were performed using the optimized jaw design to determine if there were any advantages to rotating one jaw 180°. Table 11 gives the results of this testing. Three breaks were made with both the 2 inch 1,000 lb ribbon and the 1-1/8 inch 13,500 lb webbing using an S-type specimen wrap. In both cases, a loss in strength was found. This procedure was not expected to cause a loss in strength. However, insertion of the specimen in the jaws and checking for accurate alignment is much more difficult with the jaws in this configuration. This could have resulted in some misalignment which may have caused the loss in strength. Another problem associated with this wrapping configuration is that the full 12 inches of specimen free length is not visible from one side of the line of action. This makes photographic measurement of extension more difficult and less accurate due to the reduced visible free length. This technique is therefore not recommended for testing Kevlar woven fabrics with double pin jaws. However, as in the case of the hesitation technique discussed previously, it may be used in an attempt to discourage bad breaks should problems arise.

TABLE 11

BREAKING STRENGTH VALUES FOR TWO DIFFERENT KEVLAR 29 STRUCTURES TENSILE TESTED WITH AND WITHOUT S-TYPE SPECIMEN WRAPPING TECHNIQUE USING OPTIMUM JAW CONFIGURATION

		1-1/8 Inch 13,500 Lb Kevlar 29 Webbing Coated with PVB-Roll G	2 Inch 1,000 Lb Kevlar 29 Ribbon Roll B
With S-type Wrap		15,400	900
		15,400	910
		15,300	850
	Average	15,370	887
Without S-type Wrap (from Table 6)		15,300	1,050
		15,900	1,020
		15,700	1,030
			990
			1,020
	verage	15,630	1,022

All values in lb.

Crosshead speed for all tests was 1 inch per minute.

SECTION IX

EVALUATION OF OPTIMIZED JAWS AND TECHNIQUE

All of the seven Kevlar constructions were tested using the optimized jaws and techniques described in the previous sections. Table 12 presents the results of this test series. A minimum of ten tests was performed with each material. Where there was more than one roll of a material, five tests were performed using material from each roll. This allows comparison of variability from roll to roll as well as variability within each roll. Data base values presented in Table 2 were found using the same rolls of material as those presented in Table 12 except for the 2 inch 1,000 lb ribbon. In this case the data presented in Table 12 was generated using material from the same roll used in the free length variations presented in Table 8. The ten tests performed with a 12 inch free length serve as the data base values for comparison with the optimized jaws and techniques.

The 2 inch 500 lb ribbon showed a slight loss in strength and increase in variability when tested with the new double pin jaws. However, variability within each roll was generally good. Breaks were the same with the new jaws as they were with the standard jaws and techniques. Random popping of warp yarns in the free length and a slow load drop was typical of all the tests performed with this material.

Breaking strength values for the 2 inch 1,000 lb ribbon when compared with the data in Table 8 proved to be unaffected by the change in jaws and technique. Breaking strength and variability were about the same in both cases. Breaks were either clean or diagonal and all were characterized by simultaneous failure of all warp yarns in the free length. This was also the case with the standard techniques.

The 1/2 inch 250 lb light webbing sustained a slight loss in breaking strength with no change in variability due to the change in testing. Breaks with this material were also characterized by nearly simultaneous failure of all warp yarns and clean or diagonal breaks in the free length.

The average breaking strength for the 1 inch 1,000 lb medium webbing was unchanged due to testing changes. However, an appreciably lower coefficient of variation was associated with the data gathered using the new jaws and techniques when compared with the data base values. Breaks in this series were sometimes poor, as several were edge breaks and nonsimultaneous failure of all warp yarns was evident even though most breaks occurred in the free length. However, some good breaks were observed and no difference in breaking strength could be directly associated with these seemingly poor breaks.

The 1 inch 6,000 lb webbing showed a slight increase in breaking strength and decrease in variability when compared with the data base values. Also, the variability within each of the two rolls was extremely low and the overall variability was artificially high due to differences between the rolls. Breaks were generally good with some partial breaks observed and most occurred at the tangent point of the specimen free length with the primary pin, the remaining breaks occurring in the free length.

TABLE 12

VALUES OF BREAKING STRENGTH FOR SEVEN DIFFERENT KEVLAR 29 CONSTRUCTIONS
TENSILE TESTED USING OPTIMIZED JAWS AND TECHNIQUE

Kevlar Material Type	Light Ribbon					Medium Ribbon	Light Web-bing	Medium Webbing		Medium Webbing		Heavy Webbing			Heavy Webbing Coated
Nominal Tensile Strength (lb)			500			1,000	250	1,000		6,000		15,000			13,500
Width (inch)			2			2	1/2	1		1		1-3/4			1-1/8
Roll	A	B	C	D	E	A	A	A	B	A	B	A	B	C	A
	390	455	410	470	435	950	322	1,200	1,180	6,150	5,850	16,600	17,000	16,600	14,600
	420	455	430	480	440	950	332	1,170	1,220	6,100	5,950	16,400	16,600	15,800	14,200
	410	465	455	465	415	920	323	1,120	1,200	6,100	5,900	16,500	17,500	17,000	14,600
	420	440	450	470	425	910	337	1,180	1,170	6,200	5,950	16,100	16,900	16,900	14,800
	420	460	420	470	465	980	327	1,160	1,170	6,250	5,800	16,400	17,100	17,200	15,000
						990	330								13,800
						940	340								14,700
						990	332								14,800
						940	324								14,700
						910	333								14,800
Group															
Average (lb)	412	455	433	471	436	948	330	1,166	1,188	6,160	5,890	16,400	17,020	16,700	14,600
S.D. (lb)	13	9	19	5	19	31	6	30	22	65	65	187	340	548	350
C.V. (%)	3.2	2.0	4.4	1.1	4.4	3.3	1.8	2.6	1.9	1.1	1.1	1.1	2.0	3.3	2.4
Type															
Average (lb)			441			948	330	1,177		6,025			16,700		14,600
S.D. (lb)			24			31	6	27		155			442		350
C.V. (%)			5.4			3.3	1.8	2.3		2.6			2.6		2.4
Reference Data Base Values															
Average (lb)			454			944	345	1,176		5,975			16,730		14,090
S.D. (lb)			20			31	6	47		250			371		536
C.V. (%)			4.4			3.2	1.8	4.0		4.0			2.2		3.8

All values in lb.
All tests performed using a jaw speed of 1 inch per minute and a specimen free length of 12 inches. Liner material used with optimized jaws for testing 2 inch 500 lb, 2 inch 1,000 lb and 1/2 inch 250 lb constructions.

Breaking strength of the 1-3/4 inch 15,000 lb heavy webbing was unaffected by the change in test methods. There was only a slight increase in variability associated with this change. Breaks were good with most being of the diagonal type in the free length and some being partial breaks with no obvious loss in strength associated with them.

The 1-1/8 inch 13,500 lb coated webbing showed both an increase in breaking strength and decrease in variability with the change in test methods. Breaks in this test series were similar to those observed in the data base testing except all of the breaks occurred either in the specimen free length or at the point of contact of the specimen free length with the snubbing surface and all breaks occurred with simultaneous failure of all warp yarns.

Although not all of the breaks in this test series were ideal, there were no bad breaks. This represents a substantial savings in both time and material since several of the constructions were subject to bad breaks which had to be discarded in the initial data base testing. Variability of results was generally better in this test series than in the data base testing. Only the 2 inch 500 lb light ribbon showed poor variability which was significantly larger than that obtained in data base testing. This ribbon is considered to be a poor construction due to its extreme sleaziness. Variability of all other results was extremely low. Only where variability in data base testing was low was there no change in variability, as with the 1/2 inch 250 lb and 1-3/4 inch 15,000 lb webbings. Even though variability in data base values was good for textile material testing, significant improvements were found in most cases.

Extreme care taken in following the test procedures outlined in previous sections of this report, especially those involving alignment of both sample and jaws, contributed significantly to the low variability in both data base testing and final testing. It is believed that this plays a major role in low variability of results as time spent on accurate alignment and careful testing is time saved in retesting when bad breaks and high variability are problems. Extensive in-house testing of Kevlar woven fabrics even before the onset of this program demonstrated this need for careful, accurate and repeatable test methods when testing Kevlar.

Breaking strength values for most of the materials did not change significantly with the change in test methods. The four lighter materials were tested with AFFDL pin jaws in the original data base testing and the light double pin jaw variations with the 2 inch 1,000 lb ribbon indicated that the particular pin configuration used did not have a large effect on breaking strength with the lighter constructions. This test series, using the optimized jaw configuration, gives further support to that indication. More substantial increases were seen with the heavier materials, specifically the 1 inch 6,000 lb and the 1-1/8 inch 13,500 lb webbings. Although these increases in rupture strength are not large, they do indicate an advantage of the optimized double pin jaw over the standard 4 inch diameter split capstan. This advantage, coupled with the extremely low variability of results and total absence of bad breaks for the wide range of materials studied, gives confidence to feelings that these test methods are totally adequate for testing all Kevlar woven narrow fabrics.

As indicated by Table 12, the optimized jaw system and tensile testing techniques did not have a significant effect on the rupture strength of most of the materials in this program. However, there are other resultants of the work in this program which are not all obvious from studying Table 12. One advantage, which is shown in Table 12, is the decrease in variability of test results associated with the change in test methods. Another advantage mentioned previously is the almost total elimination of bad breaks with a resultant saving in testing time. However, one benefit of the work in this program, which was not mentioned previously, is the adoption of one jaw system suitable for tensile testing all Kevlar woven narrow fabrics. The final, and possibly most important, resultant of this work is the application of the knowledge acquired in this program to a military specification for tensile testing Kevlar materials to be followed by all testing facilities involved in Government work.

Design of Optimized Jaws

A set of machine drawings for double pin jaws is presented as Figure 15 in this report. These jaws have been designed for testing Kevlar narrow fabrics with rated strengths up to 20,000 lb and widths up to 2 inches. In order to avoid plating for corrosion resistance, free machining stainless steel has been specified for all parts. The jaws have been designed to rest against the attachment block maintaining an approximately vertical position to facilitate easy specimen insertion and still allow for jaw alignment. The corner radii eliminate excess weight making the jaws easier to handle.

Draft Specification for Tensile Testing of Kevlar Materials

This is for insertion into section 4.4 of the Military Specifications for tapes and webbings, MIL-T-87130 and for tubular webbings, MIL-W-87127. In each specification, the test method reference in Table IV under breaking strength should be changed from 4108[2/] to 4.4.1, and footnote 2 should be deleted.

4.4.1 Tensile Tests

4.4.1.1 Jaw Design. All tensile tests must use double pin jaws of the design specified in Figure 15.

4.1.1.2 Machine Adjustment. Mount the jaws with careful attention to rotational and axial alignment. Set the speed of the moving jaw at 1 ± 1/4 inch per minute (2.5 ± 0.5 cm/min), and the initial jaw separation such that the distance between the tangent points where the specimen first touches the primary (large diameter) pins is 12 ± 0.1 inch (30 ± 0.2 cm). (See Figure 16. This should read Figure 2 for MIL-T-87130 and Figure 1 for MIL-W-87127.)

4.4.1.3 Specimen Size and Number. Each specimen shall be the full width of the tape or webbing and 60 inches (150 cm) long. Test five specimens, or enough to get five acceptable breaks.

NOTE: An acceptable break can only be defined as one which occurs in the unsupported length of the specimen between the primary pin tangent contact points or at the contact points, but not within the material which is wrapped around each double pin jaw, and which is characteristic of the material

being tested. Ideally, all the warp yarns should break simultaneously and cleanly and, when warp yarn tensions are carefully balanced in weaving, subsequent handling and testing, this will occur. Because of Kevlar's low elongation and high modulus, however, warp yarn tension unbalance can easily occur. This leads to a break in which the yarns fail sequentially or in groups, and may initiate a tearing type of failure. Breaks of this nature give a low value for breaking strength. If this type of break occurs in only one or two of the five specimens, it should be considered untypical and the test result discarded, and additional specimens tested to obtain 5 acceptable breaks. If more than two of the five breaks involve sequential yarn failure, or other undesirable breaking mode, and no testing inadequacies can be identified, weaving nonuniformities may be indicated, and the failure mode must be considered typical for the material being tested. In this case, even if all of the breaking load values exceed the specified strength, acceptance of the material or decision to reweave in an attempt to improve the failure mode must be subject to the discretion of the buyer.

It is essential that the nature of each break be carefully observed and recorded, in order that an assessment can be made of whether unacceptable breaks are due to deficiencies in weaving or in testing.

4.4.1.4 Specimen Mounting. Wrap the specimen around the primary and secondary pins of each jaw as shown in Figure 16. (This should read Figure 2 for MIL-T-87130 and Figure 1 for MIL-W-87127.) Be careful to keep all legs of the specimen in alignment with the direction of stress application, and successive wraps exactly in line. This is important to ensure uniform stress distribution in the specimen. For materials having a strength less than 500 pounds per inch of width, or for stronger materials which are not breaking acceptably, insert a double layer of cotton fabric (2-1/8" x 10", 4.4 cm x 25 cm) (Cloth, Silesia, Cotton, MIL-C-326) between the two layers of Kevlar which pass around the primary pin in both top and bottom jaws.

4.4.1.5 Report. Report the average breaking load obtained from five acceptable breaks, as well as the highest and lowest values observed. If the breaks are not all acceptable, identify and describe the nature of each unacceptable break. NOTE: Such descriptions may be "individual warp yarn breaks scattered throughout the free length of the specimen"; "break initiated at the edge(s) of the specimen followed by a rapid failure of the remaining warp yarns"; "break initiated at one edge of the specimen, followed by sequential warp yarn breaks proceeding across the specimen in the manner of a tear"; "several unbroken warp yarns remain after an otherwise acceptable break."

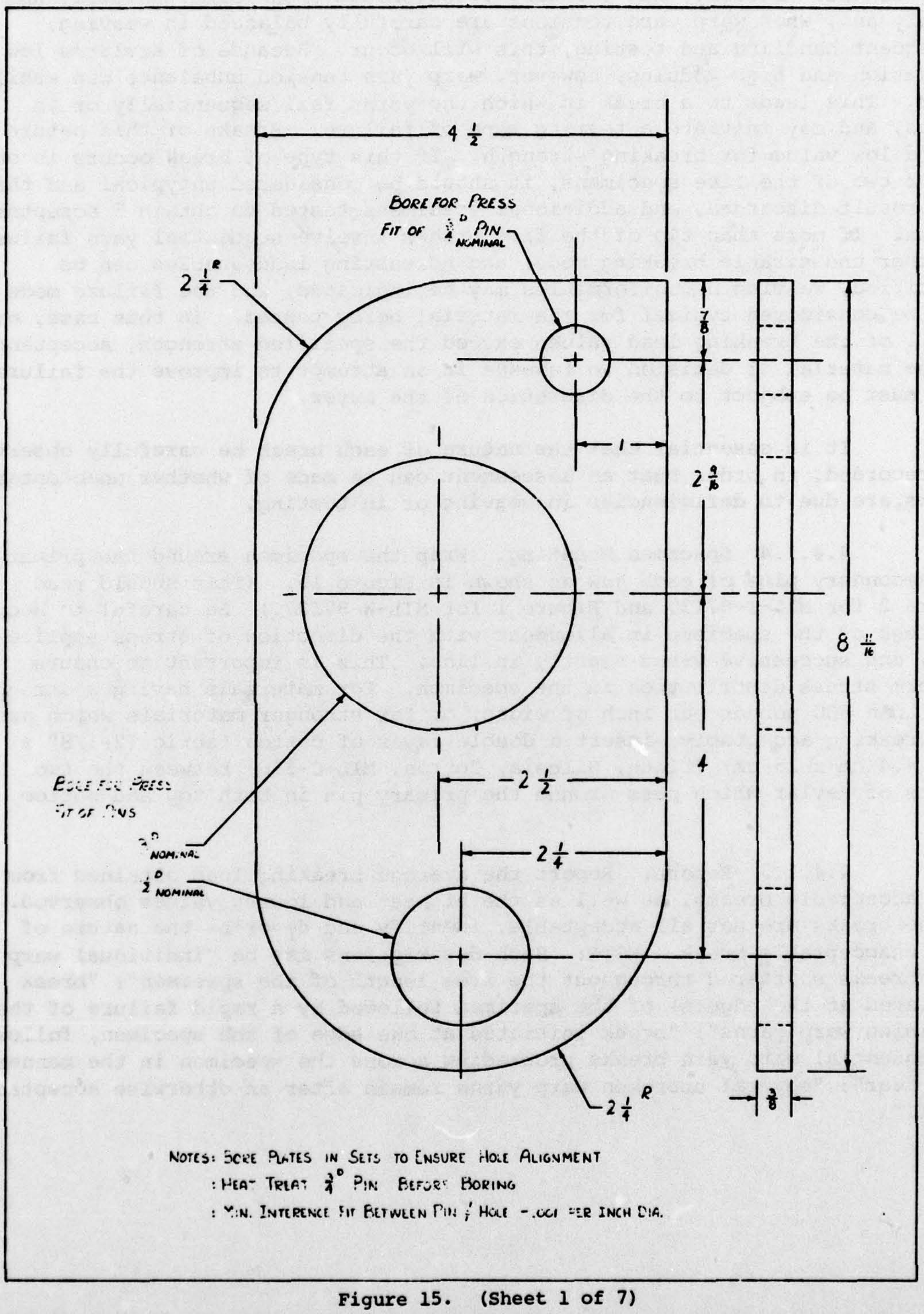


Figure 15. (Sheet 1 of 7)

Tolerance Unless Otherwise Specified

DO NOT SCALE DRAWING

S. GOODWIN 1-9-79

J DONOVAN 1-12-79

TYPE 304 STAINLESS STEEL

NONE

FRL

SIDE PLATE

1 of SHEET OF 7

A

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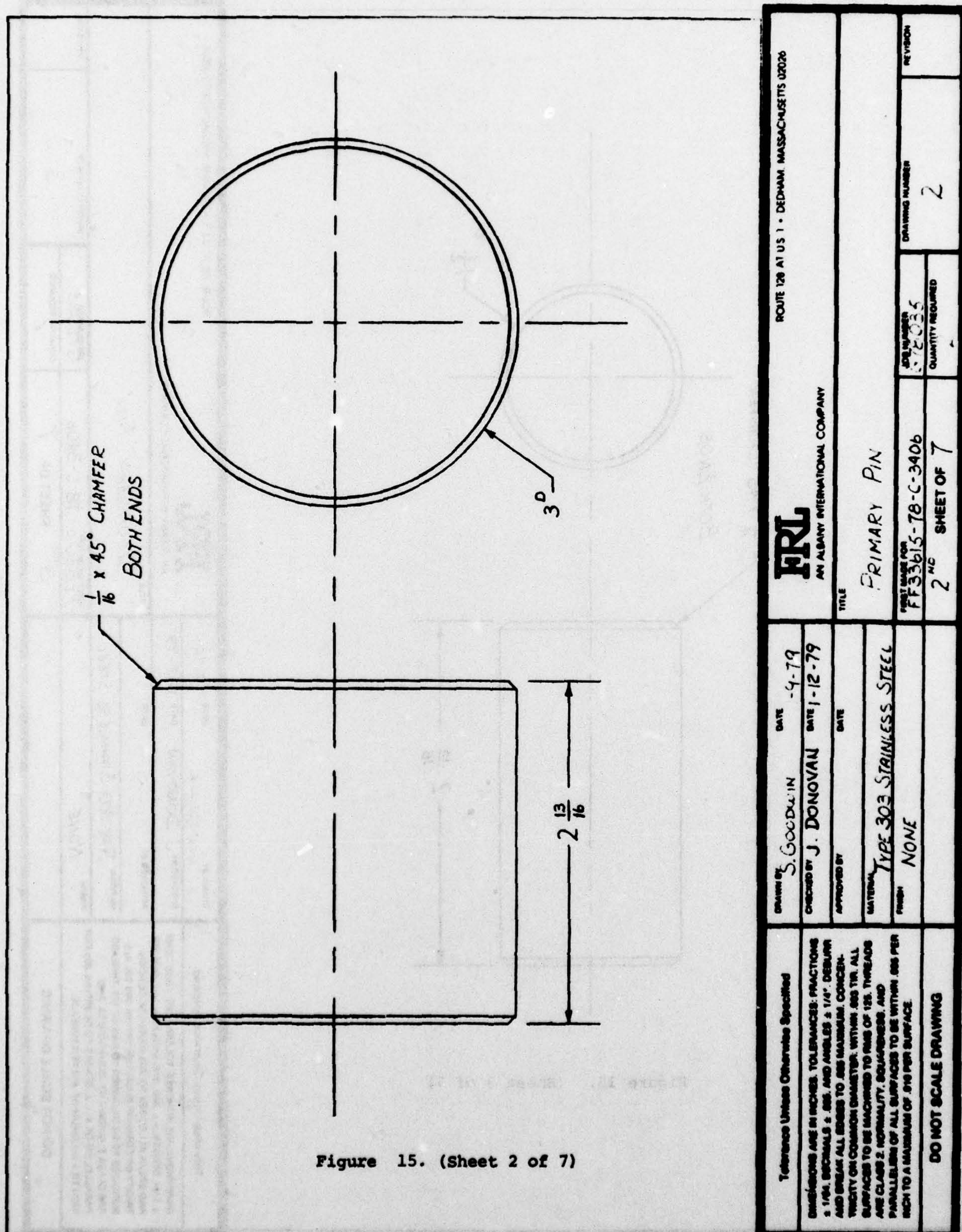

Figure 15. (Sheet 2 of 7)

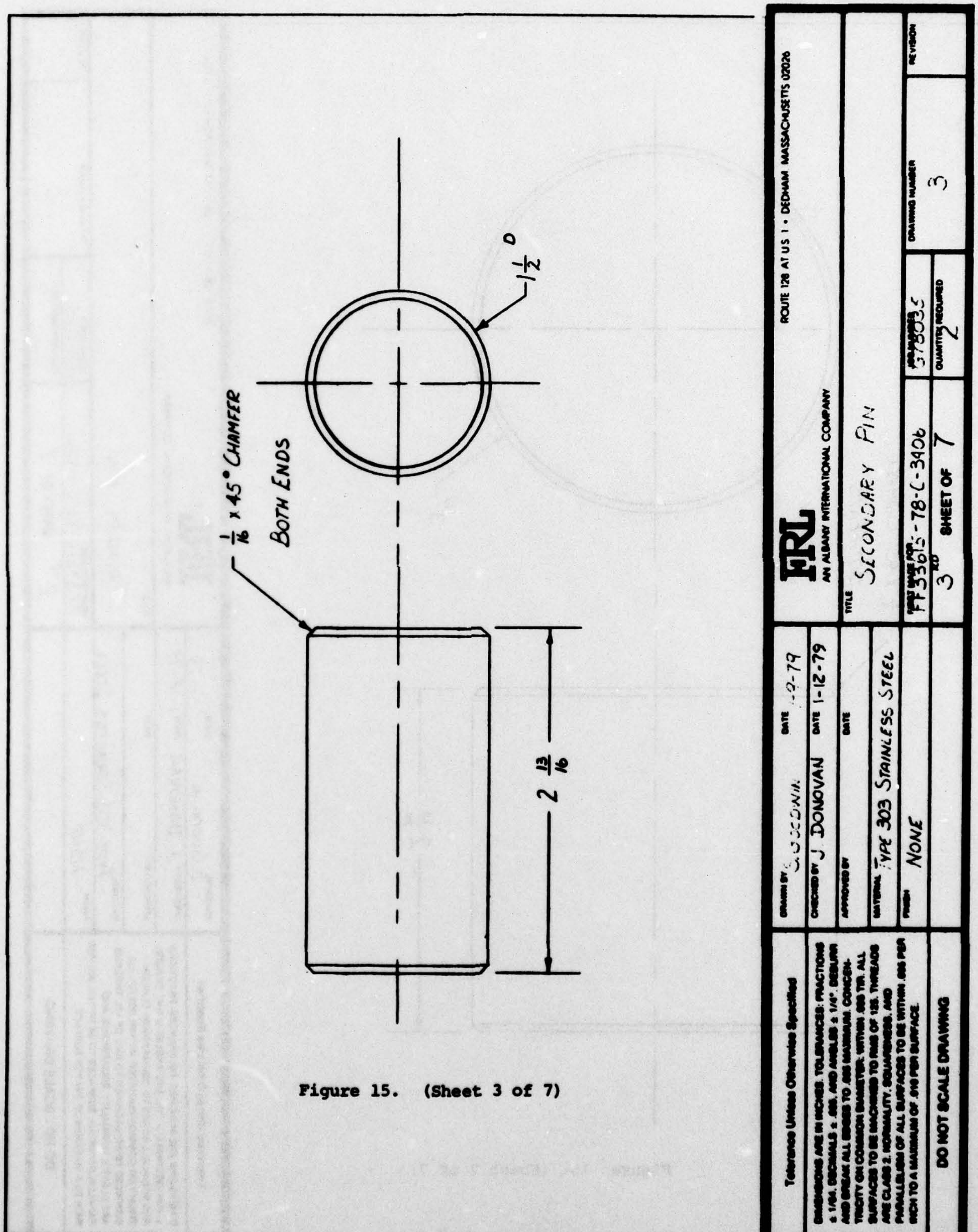

Figure 15. (Sheet 3 of 7)

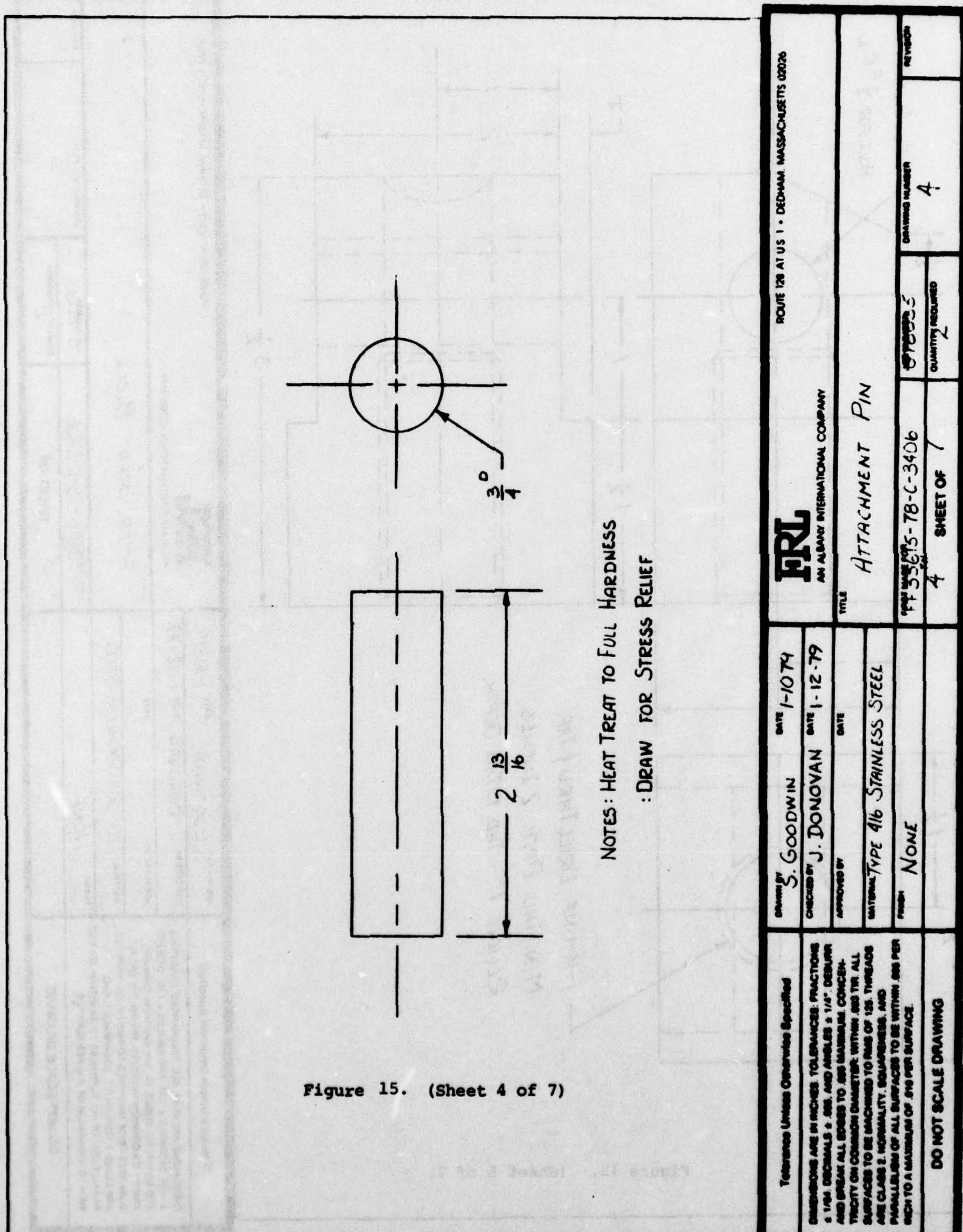

Figure 15. (Sheet 4 of 7)

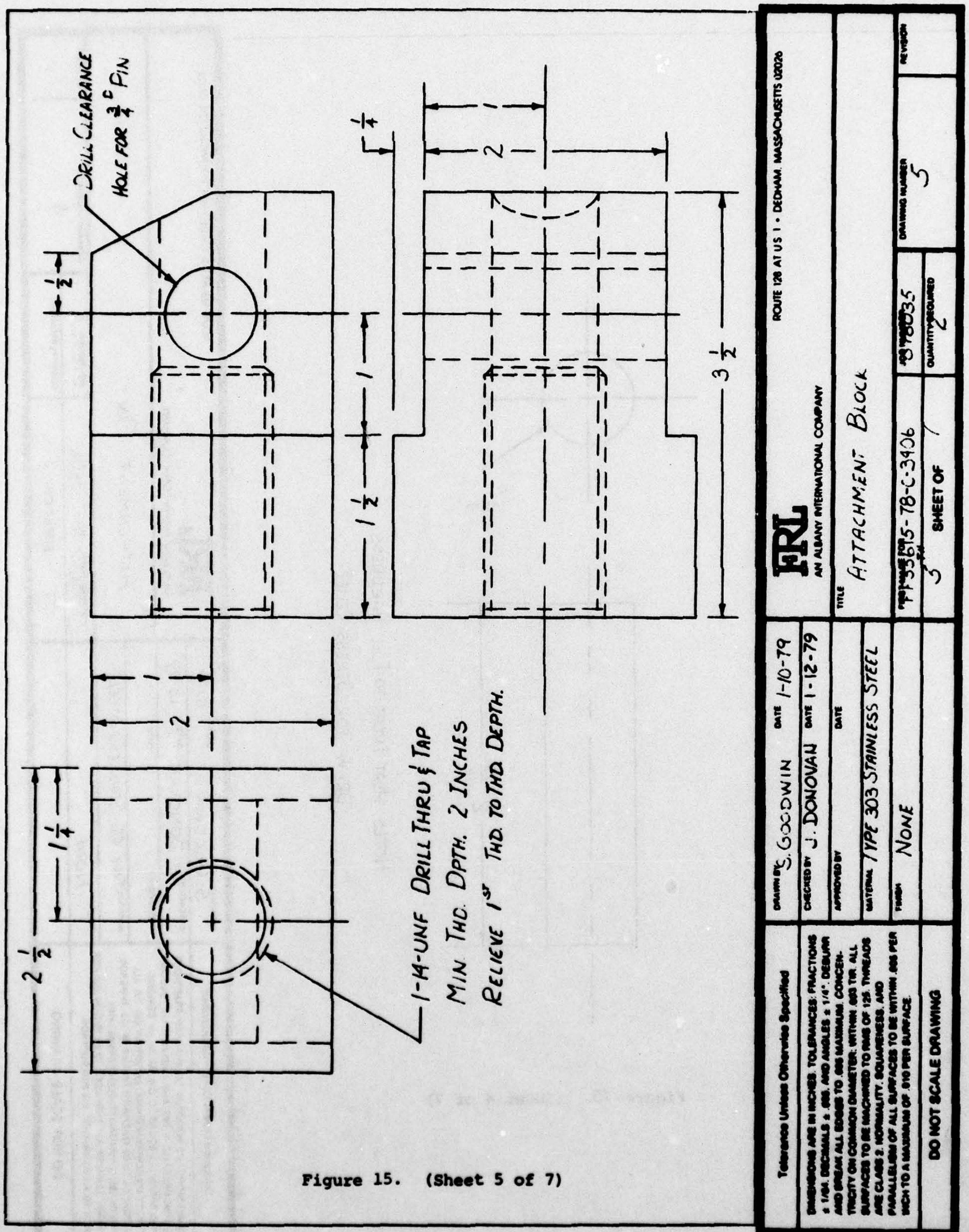

Figure 15. (Sheet 5 of 7)

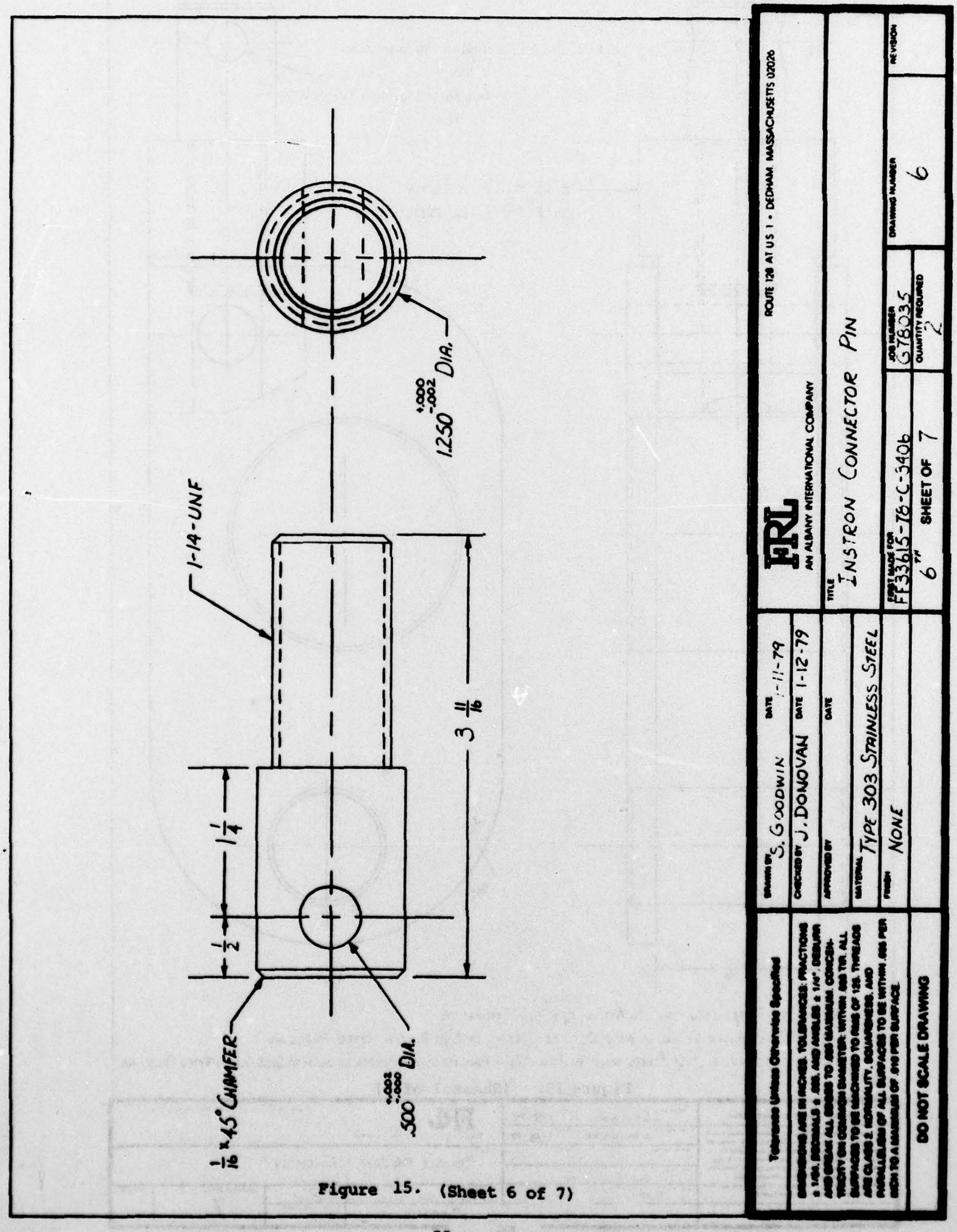

Figure 15. (Sheet 6 of 7)

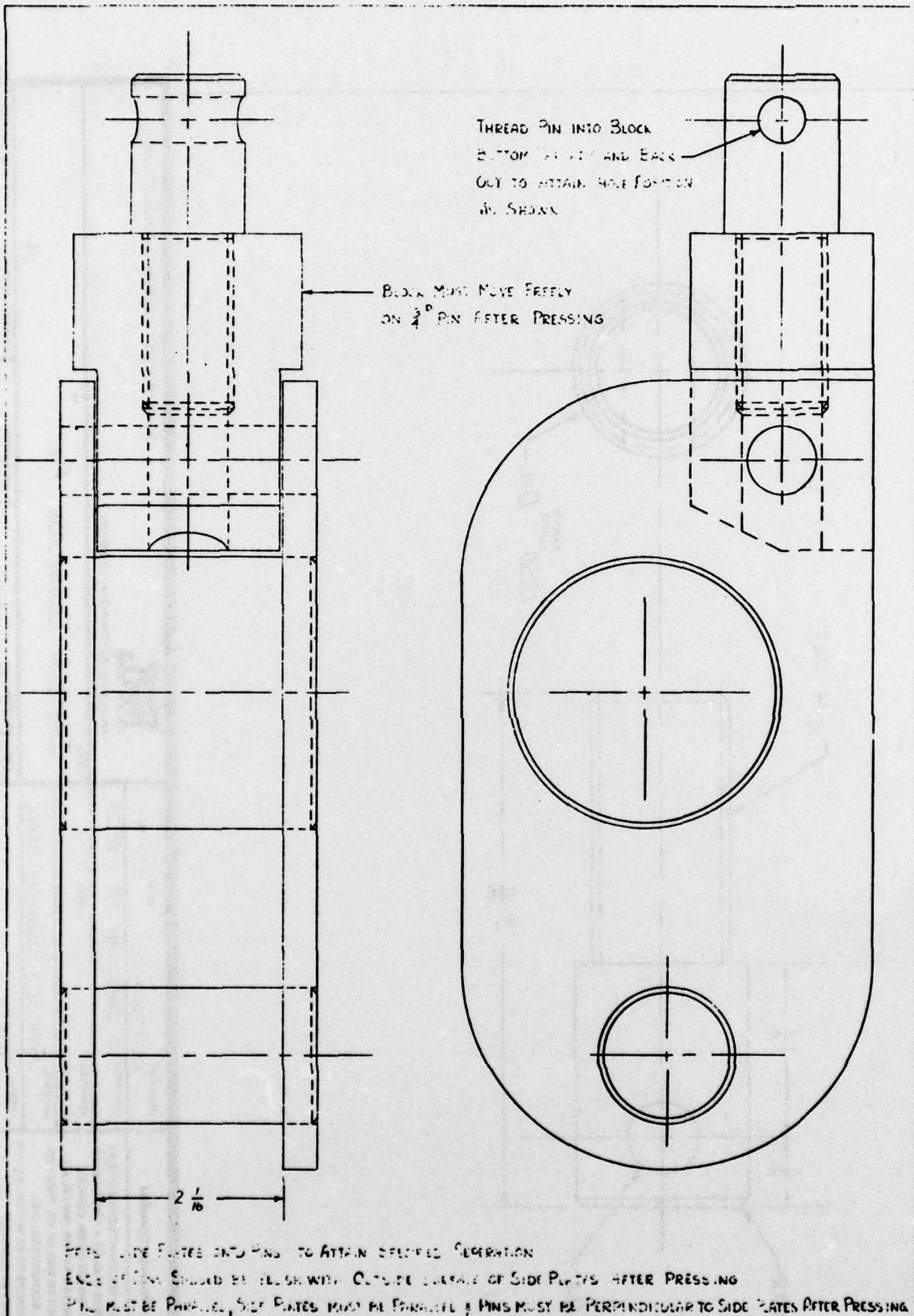

Figure 15. (Sheet 7 of 7)

Tolerance Unless Otherwise Specified	S. GOULAIN 1-12-79	FRL
	J. DONOVAN 1-12-79	
		DOUBLE PIN JAW - ASSEMBLY
DO NOT SCALE DRAWING		7

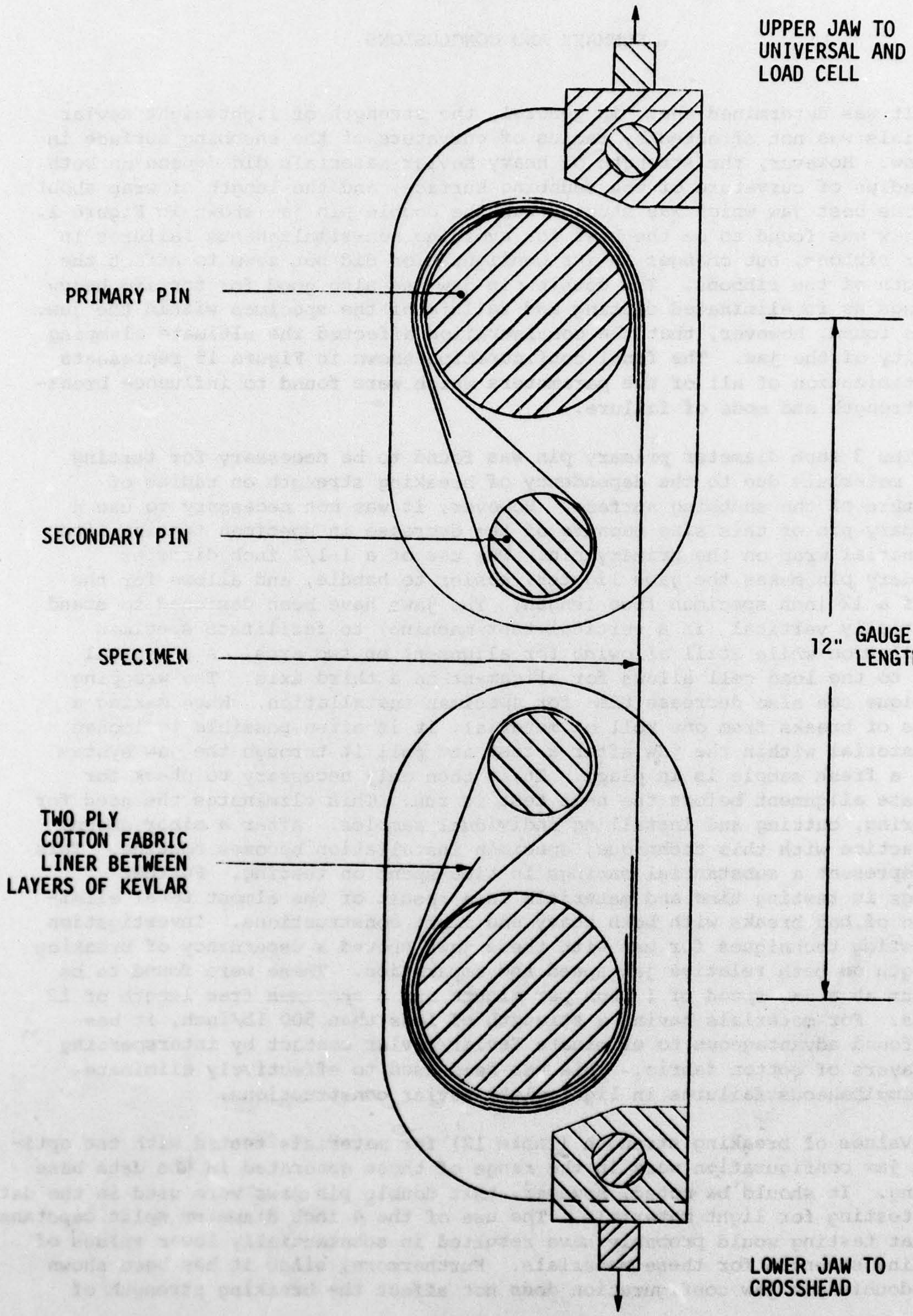

Figure 16. Test Configuration for Double Pin Jaws

SECTION X

SUMMARY AND CONCLUSIONS

It was determined that, in general, the strength of lightweight Kevlar materials was not affected by radius of curvature of the snubbing surface in the jaw. However, the strength of heavy Kevlar materials did depend on both the radius of curvature of the snubbing surface, and the length of wrap about it. The best jaw which was studied was the double pin jaw shown in Figure 1. This jaw was found to be the best for avoiding non-simultaneous failures in Kevlar ribbons, but changes in its configuration did not seem to affect the strength of the ribbons. The double pin jaw was also good for testing heavy webbings as it eliminated cutting and failure of the specimen within the jaw. It was found, however, that the configuration affected the ultimate clamping capacity of the jaw. The final configuration shown in Figure 15 represents an optimization of all of the parameters which were found to influence breaking strength and mode of failure.

The 3 inch diameter primary pin was found to be necessary for testing heavy materials due to the dependency of breaking strength on radius of curvature of the snubbing surface. However, it was not necessary to use a secondary pin of this size because of the decrease in specimen tension after the initial wrap on the primary pin. The use of a 1-1/2 inch diameter secondary pin makes the jaws lighter, easier to handle, and allows for the use of a 12 inch specimen free length. The jaws have been designed to stand essentially vertical (in a vertical test machine) to facilitate specimen installation while still allowing for alignment on two axes. A universal joint to the load cell allows for alignment on a third axis. The wrapping technique can also decrease time for specimen installation. When making a series of breaks from one roll of material, it is often possible to loosen the material within the jaw after a test and pull it through the jaw system until a fresh sample is in place. It is then only necessary to check for accurate alignment before the next test is run. This eliminates the need for measuring, cutting and installing individual samples. After a minor amount of practice with this technique, specimen installation becomes routine. This can represent a substantial savings in time spent on testing. Further savings in testing time and materials is a result of the almost total elimination of bad breaks with both heavy and light constructions. Investigation of testing techniques for use with these jaws showed a dependency of breaking strength on both relative jaw speed and separation. These were found to be optimum at a jaw speed of 1 inch per minute and a specimen free length of 12 inches. For materials having a strength of less than 500 lb/inch, it has been found advantageous to eliminate Kevlar/Kevlar contact by interspersing two layers of cotton fabric. This has been used to effectively eliminate non-simultaneous failures in lightweight Kevlar constructions.

Values of breaking strength (Table 12) for materials tested with the optimized jaw configuration were in the range of those generated in the data base testing. It should be noted, however, that double pin jaws were used in the data base testing for light materials. The use of the 4 inch diameter split capstans in that testing would probably have resulted in substantially lower values of breaking strength for these materials. Furthermore, since it has been shown that double pin jaw configuration does not affect the breaking strength of

light Kevlar constructions, no increases were expected. The variability in these test results (Table 12) is generally good, however. Extremely low coefficients of variation were found in most cases with improvements being recorded in some instances. It should also be noted that bad breaks were excluded from the average in the data base testing and simply not present in the final testing. Finally, it is our understanding that these jaws and techniques will be adopted into Military Specifications for tensile testing Kevlar woven narrow fabrics. This adoption will allow for the use of one jaw system and technique for tensile testing all Kevlar constructions having nominal strengths up to 20,000 lb and widths up to 2 inches, and will ensure good breaks, high values of breaking strength and low variability. Because these jaws can be built from standard stainless steel stock with a minimal amount of machining costs, fabrication costs should be low enough to allow all facilities involved in Government testing of Kevlar to procure a set of them. This standardization of test methods should help to avoid discrepancies between laboratories in the measured rupture strength of these materials.

Recommendations

There are some aspects of tensile testing Kevlar which have not been considered here. The most important of these is the tensile testing of Kevlar braided cords. The double pin jaws may not be suitable for testing these Kevlar constructions. Another area which may require some additional attention is the tensile testing of Kevlar broad fabrics. Although it is expected that the double pin jaws will be suitable for testing these constructions, this has not been substantiated. There may also be certain Kevlar constructions which do not fall within the range of widths and strengths of the constructions studied in this program. Whether or not the double pin jaws are suitable for testing these constructions will probably depend on the particular structure in question. Even if it is certain that the optimized jaws are not suitable, it may be possible to carefully scale the jaws to conform to the particular requirements of the material. In any case, none of these possibilities have been considered here and when testing structures outside of the scope of this program, the operator should scrutinize each break and be very careful not to accept values of breaking strength generated with these methods unless he is totally convinced that they represent an optimum value of the rupture strength of the material.

SECTION XI

REFERENCES

1. MIL-T-87130: Tape and Webbing, Textile, Para-Aramid, Intermediate Modulus. Issued 17 May, 1978.

2. This is the standard split capstan jaw used for nylon webbing. It is referred to, for example, in MIL-T-5038: Tape, Textile and Webbing, Textile, Reinforcing, Nylon and described in U. S. Army Natick Laboratories drawing no. 2-1-767: Test Jaws for High Strength Textiles, Assembly complete, Split Drum Type.

3. FRL Final Report AFML-TR-74-65, Part IV. July 1976: Design of Parachute Component Materials from Kevlar 29 and 49.

4. FRL Final Report AFFDL-TR-78-201, November 1978: Development of Kevlar 29 Decelerator Systems Materials.

5. FRL Final Report AFML-TR-70-74, June 1970: Mechanical Properties and Flammability Characteristics of Fibrous Materials. Also J. Skelton and W. D. Freeston, Jr.: The Strength of Textile Structures at High Strain Rates. Jour. Materials 6, No. 3, 1971, 643-655; idem, The Tensile Behavior of Woven Fabrics at Low and High Strain Rates, Text. Res. Jour. 41, No. 3, 1971, 187-196.

6. S. L. Goodwin, N. J. Abbott and W. R. Pinnell: Tensile Testing of Kevlar Tapes, Webbings and Ribbons. Paper presented to AIAA 6th Aerodynamic Decelerator and Balloon Technology Conference, Houston, TX, March 5-7, 1979, and contained in the printed proceedings of that conference.

7. Final Report, HASPA material development contract number N60921-75-C-0050, Martin Marietta Corporation. AD No. BO21939L.

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